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REFERENCE NO.

BELLCOMM, ING. 1100 17th ST., N. W. WASHINGTON 6. D. D.

(UNCLASSIFIED TITLE)

APOLLO HEAT SHIELD

TEST PLAN

APOLLO HEAT SHIELD TEST O(NASA-CR-130827) PLAN (Avco Corp., Wilmington, Mass.) 129 p

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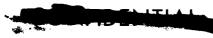
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15 June 1962

assification change to

Prepared for

NORTH AMERICAN AVIATION, INC. SPACE AND INFORMATION SYSTEMS DIVISION Downey, California



C72 72558



APOLLO HEAT SHIELD TEST PLAN

Prepared by

RESEARCH AND ADVANCED DEVELOPMENT DIVISION
AVCO CORPORATION
Wilmington, Massachusetts

RAD-SR-62-113 Letter Contract M2H43X-406012

THIS REPORT WAS PREPARED IN ACCORDANCE/WITH NAA/S&ID LETTER CONTRACT M2H43X-406012. IT IS SUBMITTED IN PARTIAL FULFILLMENT OF THE CONTRACT AND IN ACCORDANCE WITH NAA/S&ID PROCUREMENT SPECIFICATION MC364-0001 AND SID 62-420 (PARAGRAPH 4.0).

15 June 1962

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Downey, California



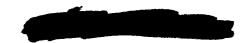
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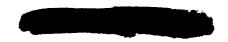
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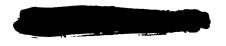
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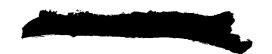




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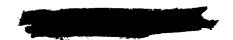




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(NOT USED)



1.0 ENGINEERING DEVELOPMENT STUDIES

1.1 HEAT RATE STUDIES (See Figure 1)

1.1.1 Convective and Radiative Heat Transfer Distribution for Basic Configuration

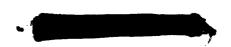
This section outlines the tests to be conducted in various shock tube facilities to determine the radiative and convective heat transfer to the reference configuration. The tests shall include determination of the effect of shape change on heat transfer distributions due to ablation and resulting angle-of-attack variations.

The first phase of this task will involve the measurement of cold-wall heat transfer rates on the "clean" reference configuration. These experiments shall be conducted in both the Avco RAD 6-1/2-and-1-1/2-inch shock tubes and shall provide convective heat transfer distributions in the windward-leeward plane, and around the body at a stagnation-point simulated velocity of 11,000 ft/sec. All models shall be instrumented with either calorimeter or thin film heat transfer gages.

A series of experiments shall be designed to investigate the importance of the radiative energy transport to the body as a function of simulated velocity. Either infrared or other heat transfer gage techniques shall be employed for these measurements. The simulated velocity and altitude regimes over which radiative heating introduces significant contributions to the total heat transfer to the vehicle shall be determined. The primary convective heat transfer program shall be continued from 28,000 ft/sec upward in velocity to the radiative threshold. Measurement of the radiative heating component only as a function of velocity shall continue up to 38,000 ft/sec. Knowledge of the radiative component of the heat transfer as a function of velocity together with spectral measurement of the surface absorptivity of the platinum heat transfer gage shall enable isolation of the radiative and convective contributions to the total heat transfer to the vehicle.

In addition to the above, the program will experimentally determine the effect on heat transfer distributions of shape changes due to ablation and resulting angle-of-attack variations. These investigations will be conducted in the Avco RAD 1-1/2-and-4-inch shock tubes. For example, variations in the corner geometry and their effect on convective heating at various angles of attack will be investigated. Other shape variations as required as the program progresses will be considered.

The testing began in May and shall be concluded in August. The test program detailed in Table I is intended to provide experimental data to aid in the





development and verification of the required analytical techniques. These tests are intended to provide aerodynamic and radiative heat transfer distributions over the velocity and altitude ranges covered by the trajectories presently under consideration.

Runs 1 to 5, refer to Table I, are necessary since, at present, the aerodynamic heating distribution is correlated in terms of the zero angle of attack at stagnation-point value and, hence, an experimental comparison is desirable.

Runs 6 to 30 are to give the complete aerodynamic heating distribution at an angle of attack of 33 degrees. While the operating conditions do not simulate the trajectories being considered, they do provide basic data which will be checked at the flight conditions of interest (see, for instance, runs 31 to 78).

Data on runs 79 to 97 are to be obtained using a total (aerodynamic plus radiative) heat transfer gage at zero angle of attack at the stagnation point. These measurements are important for the purpose of correlating the angle-of-attack measurements. This type of gage is relatively new, and it is therefore very important to test initially under conditions where existing theories are applicable. These tests and subsequent total heating measurements will cover the range of flight conditions wherein the radiative contribution is expected to be significant.

Following these tests, angle-of-attack measurements will be made (33 degrees) to obtain the total heating at the stagnation point, on the blunt face, and on the windward side of the aftercone (runs 98 to 116).

Experiments will also be made using a coated total heat transfer gage which will measure only the radiative contribution (repeat of runs 98 to 116). No attempts will be made to determine the radiative spectrum.

1.1.2 Shape Parametric Studies (Changes Due to Ablation)

The remainder of Table I is concerned with a parmeter study simulating the effects of ablation (changes in shape) and also small variations in angle of attack. The angle-of-attack range will be \pm 5 degrees. For the ablation effect study, variations in corner radius only will be examined (corner radius = 0.05, 0.10, and 0.15 blunt face diameter). This variation is expected adequately to simulate the shape changes.

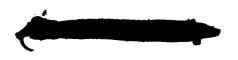


Figure 1 HEAT RATE STUDIES

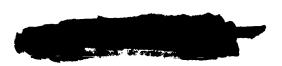


TABLE I

SHOCK TUBE TEST PLAN--APOLLO PROGRAM RODYNAMIC AND RADIATIVE HEAT TRANSFER--BASIC CONFIGURATION

ON	Remarks	Stagnation Point	Blunt Face 0-180 Plane	Corner 0-180 Plane	Blunt Face 90-270 Planes	Corner 90-270 Plane	Afterbody 0 Plane	Afterbody 0-180 Plane	Afterbody 90 Plane	Afterbody 270 Plane	Blunt Face 0-180 Plane	Corner 0-180 Plane	Blunt Face 0-180 Plane	Corner 0-180 Plane	Blunt Face 0-180 Plane	Corner 0-180 Plane	Blunt Face 0-180 Plane	Corner 0-180 Plane	Blunt Face 0-180 Plane
CONFIGURATI	Facility Model Diameter inches	1,5-inch tube/0,500																	
ERBASIC	Altitude feet	20, 000									165,000				160,000				
AT TRANSF	V ft/sec	11, 100	-								20,000		24,000	,	26,000		28,000		30,000
AERODYNAMIC AND RADIATIVE HEAT TRANSFERBASIC CONFIGURATION	Data Points per Run	1	3	2	8	2	3	٣	33	3	£.	2	3	2	6	2	8	2	3
NAMIC AND	a degrees	0	33																
AERODY	M	7.30							-		13		15		17		18		19
7	P ₁ centimeters	rv.									0,025								
	Run Nos.	1-5	6-10	11-12	13-15	16-18	19-21	22-24	25-27	28-30	31-33	34-36	37-39	40-42	43-45	46-48	49-51	52-54	55-57

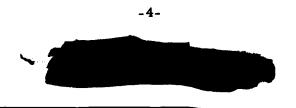


TABLE I (Cont'd)

Remarks	Corner 0-180 Plane	Blunt Face 0-180 Plane	Corner 0-180 Plane	Blunt Face 0-180 Plane	Corner 0-180 Plane	Blunt Face 0-180 Plane	Corner 0-180 Plane	Stagnation Point					Stagnation Point	Stagnation Point-Blunt Face				
Facility Model Diameter inches		6.5-inch tube/0.500						6.5-inch tube/3.00					6.5-inch tube/3.00					
Altitude feet		200, 000					·	160,000		-			100,000		-			
V _w ft/sec		20,000		56,000		30,000		28,000	30,000	32,000	34,000	36, 000	38,000	28,000	30,000	32,000	34,000	36,000
Data Points per Run	2	8	2	3	7	8	7	1	1	1	1	1	1	3	3	3	٤	3
a degrees								0					0	33				
Ms		13		17		19		18	19	20	21.5	22.8	24.2	18	19	20	21.5	22.8
P ₁ centimeters		900*0						0.010					0.010					
Run Nos.	58-60	61-63	64-66	69-29	70-72	73-75	76-78	79-82	83-85	88-98	16-68	92-94	95-97	98-100	101-103	104-106	107-110	111-113



TABLE I (Cont'd)

Remarks							
Facility Model Diameter inches							
Altitude							
V ft/sec	38,000	28,000	30,000	32,000	34,000	36,000	38,000
Data Points per Run	3	9	8	3	3	٣	3
a degrees							-
Ms	24.2	18	19	20	21.5	22.8	24.2
P ₁ centimeters							
Run Nos,	114-116	117-119	120-122	123-125	126-129	130-132	133-135

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TABLE I (Cont'd)

SHAPE PARAMETRIC STUDIES--4,0 INCH SHOCK TUBE--1,00 INCH DIAMETER MODEL

Remarks	Blunt Face 0-180 Plane	Corner 0-180 Plane	Blunt Face 90-270 Plane	Corner 90-270 Plane	Afterbody 0 Plane	Afterbody 180 Plane	Blunt Face 0-180 Plane	Corner 0-180 Plane	Blunt Face 90-270 Plane	Corner 90-270 Plane	Afterbody 0 Plane	Afterbody 180 Plane	Blunt Face 0-180 Plane	Corner 0-180 Plane	Blunt Face 90-270 Plane	Corner 0-270 Plane	Afterbody 0 Plane	Afterbody 180 Plane
r/D	0.10						0.15						0.05		_	0.05		
Altitude	50,000				- A											50,000		
V _∞ ft/sec	11, 100															11,100		
Data Points per Run	3	2	3	2	3	٤	3	2	3	2	3	3	8	7	3	7	3	3
a degrees	33												28			28		
Ms	7.30										±111					7.35		
P ₁ centimeters	ъ															r.		
Run Nes.	136-138	139-141	142-144	145-147	148-150	151-153	154-156	157-159	160-162	163-165	166-168	169-171	172-174	175-177	178-180	181-183	184-186	187-189

Remarks	Blunt Face 0-180 Plane	Corner 0-180 Plane	Blunt Face 90-270 Plane	Corner 90-270 Plane	Afterbody 0 Plane	Afterbody 180 Plane	Blunt Face 0-180 Plane	Corner 0-180 Plane	Blunt Face 90-270 Plane	Corner 90-270 Plane	Afterbody 0 Plane	Afterbody 180 Plane	Blunt Face 0-180 Plane	Corner 0-180 Plane	Blunt Face 90-270 Plane	Corner 90-270 Plane	Afterbody 1 0 Plane	Afterbody 180 Plane
r/D	0.10						0.15						0.05					
Altitude feet																		
v ft/sec																		
Data Points per Run	3	2	8	7	٣	٣	т	2	æ	2	۴	e	e	2	8	2	٣	8
a degrees											_		38					
Ms																		
P ₁ centimeters																		
Run Nos.	190-192	193-195	196-198	199-201	202-204	205-207	208-210	211-213	214-216	217-219	220-222	223-225	226-228	229-231	232-234	235-237	238-240	241 - 243



TABLE I (Concl'd)

Run Nos.	P ₁ centimeters	M _s	a degrees	Data Points per Run	V _w ft/sec	Altitude feet	r/D	Remarks
244-246				3			0.10	Blunt Face 0-180 Plane
247-249		-		2				Corner 0-180 Plane
250-252			,	3				Blunt Face 90-270 Plane
235-255	æ	7.30	38	3	11,100	50,000	0.10	Corner 90-270 Plane
256-258			-	60				Afterbody 0 Plane
259-261				8				Afterbody 180 Plane
262-264				ε.			0.15	Blunt Face 0-180 Plane
265-267				ю	-11/-			Corner 0-180 Plane
268-270				3				Blunt Face 90-270 Plane

1.2 MATERIALS PERFORMANCE TESTS (See Figure 2)

1.2.1 Ascent Heating Materials Performance Tests

The ablation performance of proposed Apollo forebody (conical) heat shield materials during ascent shall be determined by testing specimens of these materials under simulated ascent heating conditions. The low enthalpy ($10 < H/RT_O < 100$) plasma arc shall be utilized for these tests.

The plasma arc tests shall simulate ascent heating conditions as closely as possible. All tests shall be of the laminar splash nature. A description (for example, thickness) of the char layers formed shall be determined.

Estimates will be made of the amount of char which will be formed on ascent. If char forms, some specimens shall be tested in the high enthalpy air arc to determine its stability. The data shall be compared to design analysis.

1.2.1.1 Material -- Reference X5026

These tests began in May 1962 and shall continue through July 1963 as dictated by preliminary results and design requirements.

a. Test description

The following is a preliminary listing of test conditions and number of specimens for ascent heating materials response tests.

Class of Test	I*			II**		
Heat flux Btu/ft ² -sec	20	20	50	100	200	300
H/RT _o	100	10	30	60	75	100
Duration of Test seconds	20	20	20	20	10	10
Number of Specimens (Uninstrumented)	60	8	8	8	8	8
Number of Specimens (Instrumented)	5	7	7	7	7	7

^{*}Screening evaluation of ablation properties.

-10-

^{**}Comprehensive evaluation of ablation properties.

Each specimen consists of a 3/4-inch diameter cylinder of heat shield material about 2 inches in length. A silicone rubber coating about 1/4-inch thick is used to prevent side heating. A micarta holder is bonded to the rear of the specimen to facilitate mounting in the arc.

c. Specimen instrumentation

Each instrumented specimen contains three internal thermocouples located at various depths. In addition a 1/16-inch steel plate is bonded to the rear surface of the specimen and contains one thermocouple located in the center.

1.2.1.2 Material -- X5019

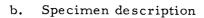
These tests began in May 1962 and shall continue through March 1963 or as dictated by preliminary results and design requirements.

a. Test description

The following is a preliminary listing of test conditions and number of specimens for the ascent heating materials response tests.

Class of Test		I			11	
Heat flux Btu/ft ² -sec	20	20	50	100	200	300
H/RT _o	100	10	30	60	75	100
Duration of Test seconds	20	20	20	20	10	10
Number of Specimens (Uninstrumented)	10	6	6	6	6	6
Number of Specimens (Instrumented)	3	2	2	3	3	3





Same as 1.2.1.1-b.

c. Specimen instrumentation

Same as 1.2.1.1-c.

1.2.1.3 Material -- Avcoat II

These tests will begin in June 1962 and continue through February 1963 or as dictated by preliminary results and design requirements.

a. Test description

The following is a preliminary listing of test conditions and number of specimens for the ascent heating materials response tests.

Class of Test		I		,	п	
Heat flux Btu/ft ² -sec	20	20	50	100	200	300
H/RT _o	100	10	30	60	75	100
Duration of Test seconds	20	20	20	20	10	10
Number of Specimens (Uninstrumented)	5	5	5	5	5	5
Number of Specimens (Instrumented)	2	2	2	2	1	1

b. Specimen description

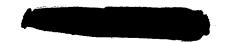
Same as 1.2.1.1-b.

c. Specimen instrumentation

Same as 1.2.1.1-c.

1.2.1.4 Material -- Adhesive Bonds, Second Generations, and Production Lot





a. Test conditions

Depending on the materials involved, these tests will employ conditions listed above. Forty specimens will be tested as shown in the schedule (see figure 2).

b. Specimen description

Same as item 1.2.1.1-b.

c. Specimen instrumentation

Same as item 1.2.1.1-c.

1.2.2 Screening Tests -- Stagnation Point -- First Pulse

The high heat flux, high enthalpy heating pulse on the afterbody of the Apollo vehicle shall be simulated, as closely as possible, on the Model PG 500 plasma arc facility. Under these simulated conditions, the ablation and thermal insulating properties of proposed Apollo afterbody materials shall be determined. Surface brightness temperatures as determined by a recording optical brightness pyrometer shall be obtained. Descriptions of all char layers (for example, thickness versus enthalpy and estimate of shear forces) shall be included.

Results from the low and high enthalpy Model 500 arcs will be correlated with OVERS arc data.

1.2.2.1 Material -- Reference Avcoat 5026

This screening began in May 1962 and shall continue as dictated by design requirements.

a. Test description

The following is a preliminary listing of test conditions and number of specimens for the material screening tests. The test conditions will be verified at a later date. All tests will be conducted using air.



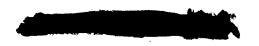
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Class of Test		I			I	I	
Heat Flux Btu/ft ² -sec	1200	1200	1200	1000	700	700	700
H/RT _o	300	200	300	200	250	200	100
Duration of Test seconds	10	10	10	10	10	10	10
Number of Specimens (Uninstrumented)	52	8	8	8	. 8	8	8
Number of Specimens (Instrumented)		7	7	7	7	6	6

Each specimen is a 3/4-inch diameter cylinder having a nominal length of 2 inches. A silicon rubber coating (on sides of specimen) will be used to prevent side heating of the specimen. A micarta tube will be bonded to one end of the specimen for support of the sample and protection of thermocouple leads when instrumented samples are evaluated.

c. Specimen instrumentation

Samples evaluated in class I tests in the Model 500 arc will have no thermocouple instrumentation. Class II tests will have both uninstrumented and instrumented samples. The instrumentation will consist of three internal thermocouples (located at various positions from the heated surface). A single thermocouple will be located in a 1/16-inch (3/4-inch diameter) steel disc bonded to the backface of the sample. Surface temperature, total radiation, and ablation characteristics shall be determined for each sample in addition to the internal temperature data (if any).





d. Model 500 arc (High heat flux test)

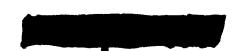
				1962			
	May	June	July	Aug	Sep	Oct	Nov
X5026	10	20	20	20	10	10	10
X5019	5	10	10	5	5	5	4
Avcoat II		5	10	10	5 .	2	2
Second Generation and Production Lots							5
Fasteners and Bonds					5	5	
	1962			19	63		
	Dec	Jan	Feb	Mar	Apr	May	June
X5026	5	5	5	5	5	5	5
X5019	3	3	3	2			
Avcoat II	2	2	2				
Second Generation and Production Lots		5	2	5	2	5	2
Fasteners and Bonds							

1.2.2.2 Material -- Avcoat 5019

This screening began in May 1962 and shall continue as dictated by design requirements.

a. Test description

The following is a preliminary listing of test conditions and number of specimens for the material screening tests. The test conditions will be verified at a later date. All tests will be conducted using air.



And the second	

Class of Test		I			II		
Heat Flux Btu/ft ² -sec	1200	1200	1200	1000	700	700	700
H/RT _o	300	200	300	200	250	200	100
Duration of Test seconds	10	10	10	10	10	10	10
Number of Speci- mens (Uninstrumented)	10	5	5	5	5	5	5
Number of Speci- mens (Instrumented)		3	3	3	3	3	3

Same as 1.2.2.1-b.

c. Specimen instrumentation

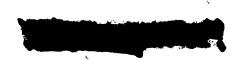
Same as 1.2.2.1-c.

1.2.2.3 Material -- Avcoat II

This screening shall begin in June 1962 and continue as dictated by design requirements.

a. Test description

The following is a preliminary listing of test conditions and number of specimens for the material screening tests. The test conditions will be verified at a later date. All tests will be conducted using air.



Class of Test		I			I		
Heat Flux Btu/ft ² -sec	1200	1200	1200	1000	700	700	700
H/RT _o	300	200	300	200	250	200	100
Duration of Test seconds	10	10	10	10	10	10	10
Number of Speci- mens (Uninstrumented)	6	4	4	4	4	4	4
Number of Speci- mens (Instrumented)		2	2	2	2	1	1

Same as 1, 2, 2, 1-b.

c. Specimen instrumentation

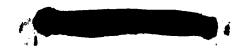
Same as 1.2.2.1-c.

1.2.2.4 Second Generation Materials, Fasteners, and Bonding Materials

These specimens will be tested under the conditions for these materials as outlined in paragraphs 1.2.2.1 through 1.2.2.3.

1.2.3 OVERS Screening Tests

Screening tests on the proposed Apollo heat shield ablative panels shall be conducted on the OVERS facility with two basic objectives: (a) To determine experimentally the amount of ablation and char-layer propagation that will occur, and (b) to compare the ablation performance of the various Apollo materials. Arc-operating conditions and time duration of tests shall be selected to simulate the average enthalpy and heat flux and total integrated heat input to the heat shield at various points on the forebody and afterbody of the Apollo vehicle for the trajectories of interest. Specimens of each material shall be instrumented with thermocouples to obtain backface temperatures and to enable identification of a temperature range with onset of charring. Approximately 10 percent of the samples will be





instrumented with three internal thermocouples, the data from which will be analyzed using Avco RAD-developed computer techniques. The depth of char-layer penetration shall be determined for all specimens by sectioning them after the arc tests. Both length change and weight change of all specimens shall be recorded. The surface brightness temperature of specimens shall be obtained with a recording optical brightness pyrometer. The nature of the char layer shall be qualitatively described.

1.2.3.1 Material -- Reference Avcoat X5026

This screening shall begin in May 1962 and continue as dictated by design requirements.

a. Test description

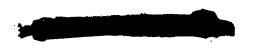
The following is a preliminary listing of test conditions and number of specimens for the materials screening tests. The test conditions will be verified at a later date.

Heat Flux* Btu/ft ² -sec	20	50	100	150	200	
H/RT _o *	300	200 450	450	150 200 300 450	300 450	
Duration of Test minutes	5 to 20	5 to 10	5 to 10	5 to 10	5 to 10	
Number of Speci- mens (Uninstrumented)	15	20	25	50	40	
Number of Speci- mens (Instrumented)						

^{*}Gas enthalpy and stagnation pressure will be adjusted to give the heat flux.

b. Specimen description

Each specimen consists of a 3/4-inch diameter center core inserted in a 1-1/2-inch diameter guard ring of the same material. The samples are nominally 1 inch long. A 0.005-inch gap between the cylinder and guard ring in which gas stagnates during





heating serves to prevent side heating and ensures one-dimensional heat flow on the heated specimen surface.

c. Specimen instrumentation

Each specimen will have a 3/4-inch diameter, 1-1/16-inch thick stainless steel disc bonded to the rear surface. A single thermocouple will be located in the center of the disc. Surface temperature and total radiation will be determined using pyrometers and thermopiles during every test. Motion pictures of the heated surface will be made of each specimen.

d. OVERS testing schedule

				1	962				
	May	June	July	Aug	Sep	Oct	Nov	Dec	2
Screening									
Avcoat X5026	20	70	50	10					
Avcoat X5019		20	30	25					
Avcoat II		10	10	5					
Second Generation				10	10	10	10	10	1
Fasteners and Bonds				10	10	10			
	1962			196	3				
	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	e
Production Lots	4	4	4	4	4	4	4	4	
Second Generation	10	10							
	****			19	63		1964		
	July	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
Production Lots	4	4	4	4	4	4	4	4	4
				19	64				
	April	May	Jun e	July	Aug.				
Production Lots	4	4	4						



1.2.3.2 Material -- Avcoat X5019

Screening tests on this material will begin in June (see figure 2).

a. Test description

The following is a preliminary listing of test conditions and number of specimens for the materials screening tests. The test conditions will be verified at a later date.

Heat Flux Btu/ft ² -sec	50	150	200	
H/RT _o	400	400	300 600	
Duration of Test minutes	5 to 10	5 to 10	5 to 10	
Number of Specimens	20	20	35	

b. Specimen description

Same as item 1.2.3.1-b.

c. Specimen instrumentation

Same as item 1.2.3.1-c.

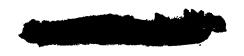
1.2.3.3 Material -- Avcoat II

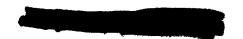
Screening tests on this material shall begin in June (see figure 2).

a. Test description

The following is a preliminary listing of test conditions and number of specimens for the materials screening tests. The test conditions will be verified at a later date.

Heat Flux Btu/ft ² -sec	20	50	150	
H/RT _o	150	400	400	
Duration of Test minutes	5 to 10	5 to 10	5 to 10	
Number of Specimens	12	7	6	





Same as item 1, 2, 3, 1-b.

c. Specimen instrumentation

Same as item 1, 2, 3, 1-c.

1.2.3.4 Second Generation Materials, Fasteners, and Bonding Materials

These specimens will be tested under the conditions for these materials as outlined in paragraphs 1.2.3.1 through 1.2.3.3.

1.2.4 Determination of Thermal Diffusivity and Surface Chemistry

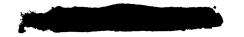
1.2.4.1 Effective Thermal Properties

Ablation tests shall be conducted in the OVERS plasma arc facility on several Apollo heat shield materials to determine (a) surface temperature and emissivity of the material, (b) rate of propagation of char layer, and (c) effective thermal properties. During much of the Apollo heating trajectory, the heat flux is low (less the 100 Btu/ft²-sec), while the gas enthalpy is about 10,000 Btu/lb ($H/RT_0 = 300$). These conditions shall be simulated by the OVERS facility. For these heating conditions, the heat shield surface recodes very slowly. As a consequence, quasi-steady-state conditions cannot be obtained and the conventional analyses in which quasi-steady state is assumed are no longer valid. These heating conditions also permit much deeper penetration of the char layer than higher heating conditions, and thus, the heat shield material absorbs the greater part of the heat internally rather than the surface ablation phenomena. For these reasons, it is necessary to perform experiments for these low heating conditions and to analyze the experiments without assuming quasi-steady state. Transient analyses are to be made and are described below. Some uninstrumented (no thermocouples) samples are to be run, but most are to be instrumented, with four thermocouples each.

a. Determination of the surface temperature and emissivity of material as a function of time, enthalpy, and heating conditions

The surface temperature is transient and can vary substantially with the heating conditions. While determining the surface temperature, the emissivity is also obtained as a function of surface temperature, enthalpy, and heating conditions. Both the surface temperatures and the emissivity values so obtained are needed for design calculations.





The surface temperature and emissivities shall be determined by three established methods: (1) surface brightness temperatures measured by a recording brightness pyrometer, (2) use of internal temperature histories measured in instrumented samples, and (3) measurement of total surface radiation with a recording spectrograph.

b. Determination of rate of propagation of char layer as a function of enthalpy and heating conditions

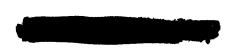
Most of the materials to be investigated char as they are heated. Charring shows that changes in the composition of the material have occurred, and thus, their mechanical, thermal, and optical properties can also change during heating. To choose the best material adequately and to design the vehicle, it is necessary to know the depth of penetration of the char layer (or layers), which is quite deep for these low heating conditions as noted above.

The rate of char propagations shall be determined by (1) utilizing instrumented specimens, and (2) running uninstrumented specimens for various lengths of time at a given set of arc conditions and sectioning them afterward to measure the depth of char penetration.

These results shall be correlated by comparing the colors of the sectioned uninstrumented samples with measured temperatures of the instrumented specimens. The measured temperature histories shall be closely examined for abrupt changes in slope of the temperature histories which may be related to certain charring phenomena. The colors in the char shall be related to the composition of the char material as determined by the thermogravimetric experiments.

c. Determination of effective thermal properties

Effective thermal properties shall be determined from specimens instrumented with thermocouples. The information that can be obtained from instrumented specimens include temperature-variable thermal diffusivity, thermal conductivity, and specific heat. Digital programs are presently available at Avco RAD for determining these quantities from transient temperature histories in heat-conducting bodies. These property values are effective values, in that they include additional phenomena (if present), such as chemical reactions and transpiration. Effective properties shall be found from data obtained covering a range of heat fluxes and enthalpy conditions to determine whether these effective properties vary with heating conditions. The values of thermal



conductivity and specific heat will be compatible with the needs of the analytical thermal analysis program.

1.2.4.2 Surface Recession Studies

The prediction of surface recession rate requires an understanding of the controlling ablation mechanisms. Depending on the material and on the environmental conditions, surface recession may be governed by oxidation or other surface chemical reaction, by mechanical shearing or erosion of the char layer, by vaporization, or by liquid-layer runoff. Splash ablation experiments shall be conducted in the OVERS arc facility and supplemented by Model 500 splash test data and 1-megawatt pipe test data to shed light on the surface recession mechanisms as a function of the re-entry environment.

Samples shall be instrumented, and surface radiation and temperature shall be monitored to enable approximate energy balance at the surface. Experiments shall be conducted at different levels of oxygen concentration to study the role of surface oxidation. High-speed movies shall be analyzed to evaluate uniformity of conditions over the ablating surface, and the importance of erosion and liquid-layer runoff.

1.2.4.3 Material -- Reference X5026

This series of tests shall begin in June and continue as dictated by design requirements.

a. Task description

The following is a preliminary listing of test conditions and numbers of specimens for each phase of this program.

Phase	A	<u> </u>			В	
Gas	Ai	r	100%	N ₂	60% N ₂	40% O ₂
Heat Flux Btu/ft ² -sec	50 t	o 100	100	200 200	100	200 200
H/RT _o	150	300	300	300	300	300
Duration of Test minutes	5 t	o 10	5 to 10	5 to 10	5 to 10	5 to 10
Number of Specimens	24	12	4	4	4	4

Each specimen consists of a 3/4-inch diameter center core inserted in a 1-1/2-inch diameter guard ring of the same material.

The samples are nominally 1 inch long. A 0.005-inch gap between the cylinder and guard ring in which gas stagnates during heating serves to prevent side heating and ensures one-dimensional heat flow on the heated specimen surface.

c. Specimen instrumentation

Each specimen for phase A (thermal diffusivity determination) shall contain four thermocouples located at various depths from heated surface. Surface temperatures and total radiation shall be determined using pyrometers, thermopiles, and spectrographic means during every test. Motion pictures shall be taken of the heated surface of each sample.

d. OVERS testing schedule

				1962	·····		
X 5026	May	June	July	Aug	Sep	Oct	Nov
Phase A			8	6	4	2	
Phase B			4	4	4	4	
X5019							
Phase A	4	4	4	4	4		4
Phase B		2	2	2	2	2	4
Avcoat							
Phase A	2	4	4	4	4	2	
Phase B			· · · · · · · · · · · · · · · · · · ·	2	4		2
Total	6	10	22	22	22	10	10

1.2.4.4 Material -- X5019

Thermal property tests on this material shall begin in June (see figure 2).

a. Test description

The following is a preliminary listing of test conditions and number of samples.



Phase	A			В		
Gas	Ai	r	100% N ₂	60 %	% O ₂	
Heat Flux Btu/ft ²	50	100	100	200	100	200
H/RT _o	150	300	300	300 200	300	200 300
Duration of Test minutes	5 to 10	5 to 10	5 to 10	5 to 10	5 to 10	5 to 10
Number of Specimens	10	10	2	4	2	4

Same as item 1.2.4.3-b.

c. Specimen instrumentation

Same as item 1.2.4.3-c.

1.2.4.5 Material -- Avcoat II

Thermal property tests on this material shall begin in June (see figure 2).

a. Test description

The following is a preliminary listing of test conditions and number of specimens for the material. The test conditions will be verified at a later date.

Phase	A	<u> </u>			В	
Gas	Ai	ir	100% 1	N2 6	60% N2 40°	% O ₂
Heat Flux Btu/ft ² -sec	50	100	100	200	100	200
H/RT _o	150	300	300	200	300	200
Duration of Test minutes	5 to 10	5 to 10	5 to 10	5 to 10	5 to 10	5 to 10
Number of Specimens	8	8	2	2	2	2



Same as item 1.2.4.3-b.

c. Speciment instrumentation

Same as item 1.2.4.3-c

1.2.5 Laminar and Turbulent Pipe Tests

The 10-megawatt arc facility shall be used to conduct pipe tests (both laminar and turbulent) to aid in evaluation of thermal stresses, char strength, and material response to ascent heating.

A transition section from the pipe apparatus to the vacuum system shall be constructed. The transition section is a prerequisite to the performing of laminar pipe tests. Calorimeter models of the various shapes tested shall be constructed to determine the heat fluxes to these shapes under test conditions. Models shall be instrumented with thermocouples, strain gages, and displacement gages.

Surface recession, surface radiation, and brightness temperature shall be recorded as functions of time for splash tests. All specimens shall be sectioned after test, the depth of char determined, and the char characterized. High-speed movies shall be taken of the ablation experiments.

The shear strength of the char layers of the various materials shall be determined by finding the minimum shear level which will keep a char layer from forming. Surface recession data shall be compared with OVERS and Model 500 arc data to determine and evaluate the ablation mechanisms of importance in these differing environments.

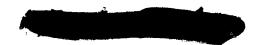
Data on ablation around gaps and steps shall be compared with related data obtained on other programs to check consistency and to determine whether previously developed correlations are applicable. The strain and displacement gage and thermocouple data shall be supplied for thermal stress evaluation.

1.2.5.1 Reference -- Avcoat 5026-22

Testing of this material shall begin in June 1962 and continue as required by design considerations.

a. Test description

Tests shall be of two types:



1) Pipe tests

To aid in thermal stress and char strength determination.

2) Splash tests

To aid in evaluation effects of cutouts and protuberances on material performance.

The following is a preliminary listing of test conditions and number of specimens for these two types of test. These test conditions shall be verified at a later date and shall be strongly influenced by preliminary results.

Heat Flux Btu/ft ² sec	100	300	600	1000
H/RT _o	50	50	50	50
	200		350	200
	350	350		350
Duration of Test, minutes	5	2	1	1/2
Number of Specimens				
Pipe	10	6	6	10
Splash	8	6	6	8

b. Specimen description

- 1) Pipe samples shall be 5 to 15 inches long, with a 1-1/4-inch inside diameter and a 2-1/2-inch outside diameter. Samples shall be bonded to a 1/16-inch thick stainless steel outer sleeve. The ends of the pipe test samples shall be machined so as to fit in the 10-megawatt pipe test rig and give an adequate seal.
- 2) Splash samples shall be about 6 inches in diameter. The geometry of the splash sample shall vary depending on the vehicle location of the section of heat shield under test.





c. Specimen instrumentation

1) Pipe tests

The specimens shall be instrumented with six thermocouples located at various depths from the inner pipe wall. A single thermocouple shall be located in the center of the outer stainless steel sleeve. One-half of the specimens shall be instrumented with several strain gages, the number and location to be determined.

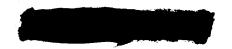
2) Splash tests

The specimens shall be instrumented with six thermocouples located at various depths from the surface and in the vicinity of the cutout or protuberance of interest. A thermocouple shall also be placed in the center of the backup material behind the cutout or protuberance. Surface brightness temperature and total radiation shall be determined using pyrometers and thermopiles during every test.

d. Ten-megawatt testing schedule

				1962						1963		
	May	June	July	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr
Pipe												
X5026	•	4	6	8	6	6	2					
X5019		2	2	3	3	2	1					
Avcoat II		1	2	3	2	2	1					
Second Generation					1	3	4	2				
Adhesive Bonds		2	4	6	4	3	1					
Production Lots							2	4	4	4	4	4
Splash												
X5026		2	4	6	6	8	2					
X5019		3	6	6	6	4	2					
Avcoat II		1	1	2	2	2	1					
Adhesive Bonds		2	6	10	10	8	4					
Second Generation					1	3	4	2				





				196	2		-				1	963			
	May	June	July	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July
Pipe															
Produc- tion Lots	4	4	4	4	4	4	4	4	4	4	4	4	4	4	2

1.2.5.2 Material -- Avcoat II

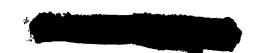
Items 1. 2. 5. 2-a-d are same as items 1. 2. 5. 1-a-d except for the following:

Heat Flux, Btu/ft ² sec	100	300
H/RT _o	50	50
	200	350
	350	
Duration of Test, minutes	5	2
Number of Specimens		
Pipe	7	4
Splash	6	3

1. 2. 5. 3 Material -- Avcoat 5019

Items 1.2.5.3 a-d are same as items 1.2.5.1 a-d except for the following:

Heat Flux, Btu/ft ² sec	100	300	600	
H/RT _o	50	50	50	
	200			
	350	350	350	
Duration of Test, minutes	5	2	1	
Number of Specimens				
Pipe	7	4	2	
Splash	15	8	4	



1.2.5.4 Material -- Adhesive Bonds

Testing of this material shall begin in June 1962 and continue as required by design considerations.

a. Test description

Tests shall be of two types:

1) Pipe tests

To evaluate adhesive performance as to bond temperature stability ablation characterisits when exposed, and bond adhesion under thermally induced stresses.

2) Splash tests

Same objective as pipe tests with addition of factor of evaluating effect of cutouts and protuberances on material performance.

The following is a preliminary listing of test conditions and number of specimens for these two types of tests. These test conditions shall be verified at a later date and shall be strongly influenced by preliminary results.

Heat Flux, Btu/ft ² sec	100	300	600	1000
H/RT _o	50	50	50	50
	200			200
	350	350	350	350
Duration of Test, minutes	5	2	1	1/2
Number of Specimens				
Pipe	6	4	4	6
Splash	12	8	8	12

-30-



1.2.5.5 Material -- Second Generation

Items 1.2.5.5 a-d are same as items 1.2.5.1 a-d except for the following:

Heat Flux, Btu/ft ² sec	100	300	600	1000
H/RT _o	200			200
	350	350	350	350
Duration of Test, minutes	5	2	1	1/2
Number of Specimens				
Pipe	3	2	2	3
Splash	3	2	2	3

1.2.5.6 Material -- Production

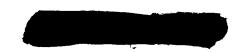
Testing of production tiles shall begin in November 1962 and continue through the production of the eighth vehicle. Approximately 10 percent of production shall be sampled for testing.

a. Test description

Tests shall be pipe tests to check material ablation performance.

The following is a preliminary listing of test conditions and number of specimens; they shall be verified at a later date.

Heat Flux, Btu/ft ² sec	100	300	1000
H/RT _o	50 350	350	350
Duration of Test, minutes	5	2	1
Number of Specimens Pipe	20	20	40



b. Specimen description

Pipe samples shall be 5 inches long with a 1-1/4-inch inside diameter and a 2-1/2-inch outside diameter. Samples shall be bonded to a 1/16-inch thick stainless steel outer sleeve. The ends of the pipe test samples shall be machined so as to fit in the 10-megawatt pipe test rig with an adequate seal.

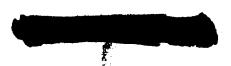
c. Specimen instrumentation

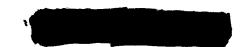
Specimen shall be instrumented with two thermocouples located in the outer stainless steel sleeve.

1.2.6 Measurement of Transmittance, Reflectance, and Emissivity

The optical properties (transmittance, reflectance, and emissivity) of proposed Apollo heat shield materials shall be measured experimentally. The purpose of these measurements shall be to obtain the necessary physical properties for calculations of (1) surface temperature of the heat shield during its flight through space, and (2) internal radiation in the heat shield during ascent, space flight, and re-entry. The measured optical properties shall also aid in the calculation of the surface temperature of the heat shield during re-entry. The measurement to be made, and tasks to be performed are as follows:

- a. Spectral measurement of diffuse reflectance from about 0.2 to 2 microns at room temperature for various thickness of a material.
- b. Spectral measurement (0.2 to 2 microns) of diffuse transmittance at room temperature for various thickness of a material.
- c. Calculation of spectal absorptivity (and emissivity) from the data obtained in items (a) and (b) above. Emissivity shall be calculated and compared with the values obtained from the ablation experiment.
- d. Measurement of hemispherical emittance as a function of temperature, from -80 degrees to as high a temperature as practical. The results are to be correlated with those of item (c) above, and with those from the ablation experiments.
- e. The ratio of solar absorptivity to hermispherical emissivity determined for various temperatures from -80 degrees to as high a temperature as practical when apparatus has been constructed. Construction and checkout shall be the initial phase.





1.2.6.1 The testing began in May and shall continue as dictated by design requirements.

a. Test description

The following lists the number of specimens to be tested in each test for virgin material and char properties determination:

Material	Property	Number of Specimens
Avcoat X5026	Transmittance	60
	Reflectance	60
	Emissivity	60
Avcoat II	Transmittance	18
	Reflectance	18
	Emissivity	18
Avcoat X5019	Transmittance	18
	Reflectance	18
	Emissivity	18
Second Generation	Transmittance	20
	Reflectance	20
	Emissivity	20
Production Lots	Transmittance	20
	Reflectance	20
	Emissivity	20

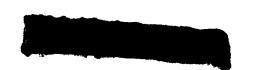
Schedule

Avcoat X5026

	1			1962			
	May	June	July	Aug	Sep	Oct	Nov
Transmittance	5	10	10	10	10	10	5
Reflectance	5	10	10	10	10	10	5
Emissivity	5	10	10	10	10	10	5

Avcoat X5026 (char)

Same as above.



Avcoat X5019

		1962							
	May	June	July	Aug	Sep	Oct	Nov		
Transmittance	2	3	3	3	3	3	1		
Reflectance	2	3	3	3	3	3	1		
Emissivity	2	3	3	3	3	3	1		

Avcoat X5019 (char), Avcoat II, and Avcoat II (char)

Same as Avcoat X5019.

Schedule

Second Generation

1962								
Aug	Sep	Oct	Nov	Dec				
2	5	5	5	3				
2	5	5	5	3				
2	5	5	5	3				
	2	2 5	Aug Sep Oct 2 5 5 2 5 5 2 5 5	Aug Sep Oct Nov 2 5 5 5 2 5 5 5 2 5 5 5				

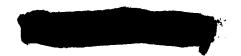
Second Generation (char)

Same as above.

Production Lots

		1962		1963					
	Nov	Dec	Jan	Feb	Mar	Apr	May	June	
Transmittance	1	1	1	1	1	1	1	1	
Reflectance	1	1	1	1	1	1	1	1	
Emissivity	1	1	1	1	1	1	1	1	

	1962						1963		
July	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	
1	1	1	1	1	1	1	1	1	
1	1	1	1	1	1	1	1	1	
1	1	1	1	1	1	1	1	1	
	July 1 1 1	July Aug 1 1 1 1 1 1			<u> </u>			2,02	



Production Lots

	1963								
	Apr	May	June						
Transmittance	1	1	1						
Reflectance	1	1	1						
Emissivity	1	1	1						

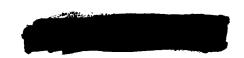
1.2.7 Materials Response to Combined Radiative and Convective Heating on the Blunt Face

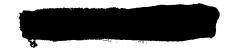
Specimens of proposed heat shield materials shall be subjected to combined convective and radiative heating tests in the OVERS arc facility. The thermal response of the materials in these tests shall be compared with the results of other tests without radiative heating.

About one-half of the specimens shall be instrumented with three internal thermocouples and one thermocouple in a thin metal plate which simulates the backup material. The remaining specimens shall have single thermocouples in the backup plate. In addition to the internal temperature response, the surface recession, surface radiation, and brightness temperature shall be recorded as functions of time during the tests. Each test shall be terminated when the backface temperature reaches a predetermined value. All specimens shall be sectioned after testing. High-speed movies shall be taken of the ablation experiments.

The thermocouple data shall be analyzed to see whether the surface radiation and surface temperature from extrapolated thermocouple data are consistent (gas radiation may be present). The thermocouple data shall be analyzed and compared with similar data from runs without radiation heating to determine if the incident radiation is all absorbed at the surface or is absorbed in depth.

The effect of the combined radiative and convective heating on ablation rate and char propagation rate shall also be determined. The rate of char propagation shall be determined as a function of time from internal thermocouple readings, and at the conclusion of the test, by sectioning, the specimen and measuring the char depth.





1.2.7.1 Material -- Reference X5026-22

Testing of this material shall begin in July 1962 and continue as required by design requirements.

a. Test description

The following is a listing of test conditions and number of specimens for the radiative convective tests.

Convective Heat Flux, Btu/ft ² sec	50	100	150	200
Radiative Heat Flux, Btu/ft ² sec	20 50	30 100	50 150	70 200
H/RT _o	400	400	400	400
Time, minutes	5	5	5	5
Number of Specimens	24	24	24	24

b. Specimen description

Each specimen consists of a 3/4-inch diameter center core inserted in a 1-1/2-inch diameter guard ring of the same material. The samples are nominally 1-inch long. A 0.005-inch gap between the cylinder and guard ring in which gas stagnates during heating seems to prevent side heating and ensures one-dimensional heat flow on the heated specimen surface.

c. Specimen instrumentation

Each specimen shall contain three thermocouples located at various depths from the surface. Each specimen shall have a 3/4-inch diameter,1/16-inch thick stainless steel disk bonded to the rear surface. A single thermocouple shall be located in the center of the disk. Surface temperature shall be estimated, and total radiation shall be determined from spectrometer, pyrometer, and thermopile data for each test.



d. OVERS testing schedule

	1962								
	July	Aug	Sep	Oct	Nov	Dec			
X5026	4	10	20	5	2				
X5019		5	10	3	2				
Adhesive bonds		5	10	2	2				
Second Generation				5	6				

1.2.7.2 Material -- X5019

Combined radiation-convection testing of this material shall begin in August. The test conditions, specimen description, specimen instrumentation, and scheduling shall be the same as given for Avcoat X5026 in items 1.2.7.1 a-d.

1.2.7.3 Material -- Adhesive Bonds

Combined radiation-convection testing of this material shall begin in August. The test conditions, specimen description, specimen instrumentation, and scheduling shall be the same as given for Avcoat X5026 in items 1.2.7.1 a-d.

1.2.7.4 Second-Generation Materials

Combined radiation-convection testing of this material shall begin in October. The test conditions, specimen description, specimen instrumentation, and scheduling shall be the same as given for Avcoat X5026 in items 1.2.7.1 a-d.

1.2.8 Materials Response to Simulated Trajectories

Heat shield materials shall be subjected to simulated trajectories and environments in a modified OVERS facility. These tests shall provide verification of design calculations and on material performance. The facility modifications shall be made in three general areas.

Specimens of the heat shield materials shall be subjected to simulated programmed trajectorics. Response shall be monitored by determining the extent of surface recession, the extent of charring as determined by

sectioning and by internal thermocouple response, and the backface temperature rise. Surface temperature shall be monitored as a function of time, and movies shall be taken to establish ablation as a function of time. Calorimeter tests shall check the programmed environment. Tests shall be made with combined radiative-convective heat inputs, where appropriate materials shall be evaluated for performance under a range of simulated environments characterisite of the regions of the vehicle for which the use of the material is contemplated. Most specimens shall be heat shield bond-structure composites, and the backface and internal temperatures shall be measured with thermocouples in all tests. Particular attention shall be paid to the ability of the char layer formed in the initial heating pulse to servive the cooling and subsequent heating characteristic of the skipout trajectories.

Data shall be analyzed and compared with predictions based on constant environment arc exposure tests. Backface and internal temperature time histories and ablation data shall be compared with heat shield design program predictions.

1.2.8.1 Material -- Reference X5026

These tests shall begin in July 1962 and continue through February 1964 or as dicated by preliminary results and design requirements.

a. Test description

The following is a listing of test conditions and number of specimens for the materials response to simulated typical trajectories. All tests shall be conducted in a sumulated air atmosphere. There shall be 7 simulated trajectories with 16 tests per trajectory.

Heat Flux, Btu/ft ² sec	20	100	200	200	100	50	80
H/RT _o	700	700	300	200	350	400	250
Time, seconds	0 to 30	30 to 60	60 to 90	90 to 200	200 to 400	400 to 800	800 to 1200

b. Specimen description

Each specimen consists of a 3/4-inch diameter center inserted in a 1=1/2-inch diameter guard ring of the same material. The samples are nominally 1-inch long. A 0.005-inch gap between the cyclinder and guard ring in which gas stagnates during heating serves to prevent side heating and ensures one-dimensional heat flow on the heated specimen surface.



c. Specimen instrumentation

Each specimen shall contain three internal thermocouples located at various depths from the front surface. In addition, each specimen shall have a 1-1/16-inch thick stainless steel disk bonded to the rear surface.

1.2.8.2 Material -- Avcoat X5019

Tests on this material shall begin in July (see figure 2).

a. Test conditions

The following is a listing of test conditions and number of specimens for the materials response to simulated trajectory tests. Seven trajectories shall be employed with eight specimens per trajectory. These test conditions shall be verified at a later date.

Heat Flux, Btu/ft ² sec	30	100	200	50
H/RT _o	400	400	300	150
Time, seconds	0 to 40	40 to 60	60 to 100	100 to 130
Number of Specimens	8	8	8	8

b. Specimen description

Same as item 1.2.8.1-b.

c. Specimen instrumentation

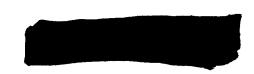
Same as item 1.2.8.1-c.

1.2.8.3 Material -- Avcoat II

Tests on these materials shall begin in August 1962 (see figure 2).

a. Test conditions

The following is a listing of test conditions and number of specimens for the materials response to simulated typical trajectory tests. Seven trajectories shall be employed with five specimens per trajectory. These test conditions shall be verified at a later date.



Heat Flux, Btu/ft ² sec	20	100	50	
H/RT _o	4 00	300	150	
Time, seconds	0 to 60	60 to 90	90 to 120	
Number of Specimens	5	5	5	

b. Specimen description

Same as item 1.2.8.1-b.

c. Specimen instrumentation

Same as item 1.2.8.1-c.

1.2.8.4 Material -- Production Lot and Second Generation

Tests on these materials shall begin in August 1962 (see figure 2).

a. Test conditions

Depending on the material involved, simulated trajectories listed above shall be employed. Eighty-two specimens shall be tested as shown in figure 2.

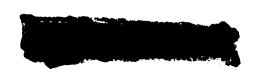
b. Specimen description

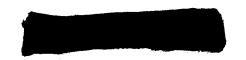
Same as item 1, 2, 9, 1-b.

c. Specimen instrumentation

Same as item 1.2.9.1-c.

d. OVERS -- Material response to simulated trajectories





		1962									
	July	Aug	Sep	Oct	Nov	Dec					
X5026	2	10	20	30	30	20					
X5019	1	5	10	15	15	10					
Avcoat II		4	5	10	10	6					
Second Generation		1	3	3	3	5					
Fasteners and Bonds		. 1	2	2	2						

	1963									
	Jan	Feb	Mar	Apr	May	June				
Production Lots	2	4	4	4	4	4				
Second Generation	2									

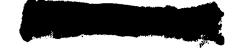
	1963							1964		
	July Aug Sep Oct Nov Dec					Jan	Feb			
Production Lots	4	4	4	4	4	4	4	4		

	Mar
Production Lots	4

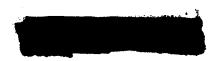
1.2.9 Micrometeoroid Impact Tests

A study is being performed to determine the need for a micrometeoroid shield for the Apollo Command Module. To achieve this end result and be in a position to define the need for a micrometeoroid shield or bumper, impact tests shall be made in various ballistics ranges, and some aggravation tests of impacted specimen shall be performed in the arcs on the specific candidate materials.





In addition to the ballistics range tests, a limited number of aggravation tests shall be made. Three pipe tests shall be performed on each candidate material. These pipes shall be made 10-inches long with ID and OD of 1-1/2 and 3-inches, respectively. The 10-megawatt arc shall be used for these aggravation tests.



A M J J J A I S TO IN ID J IF IM A IM J J J A I S TO IN ID	16 117 118 19 1 20 21 22 23 24 25 26 27 28 29 30	5 Tests					Δ	AMJJASONDJFMAMJJASOND				roduction		A M J J A S O N D J F M A M L	1963 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36
JIF MIA MUJU AISTOINID JIF IM	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15		Material - X5026 (140 Tests)	Material - X5019 (56 Tests)	Malerial - AVCOAT II (40 Tests)	Addesive Bonds, 2nd Generation Production Lot (40 Tests)		J F M A M J J A S O N D J F M	 Material - X5026 (140 Tests)	Material - X5019 (55 Tests)	Material - AVCOAT II (40 Tests)	2nd Generation and Production Lots (26 Tests)	Bonds (10 Test)	M A C O N O S A C C M W A M A I M	13 4 5 6 7 8

Figure 2 MATERIALS PERFORMANCE TESTS

MIJJJAISTOINID JIFIMIAIMIJJJAISTOINID JIFIMIAIMIJJJAISTOINID	1516 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 124 25 126 127 128 129 3	Begin Screening Tests (Average 9, h/rt - Front Face and Afterbody)	Material X5026 (150 Tests) Material	X5019 (75 Tests)	Second Generation (50 Tests) Fasteners and Bods 30 Tests	Production Materials (80 Tests)	MUJUASONDUFMAMUJUASONDUFMAMUJUASOND	Begin Testing of Thermal Diffusivity and Surface Chemistry	Material X5026 Phase A (20(Tests) Phase B (16 Tests)	Material X5019 Phase A (24 Tests) Phase B (14 Tests)	Phase A (20 Tests)Phase B (8 Tests)		IJ JASSOND JEMAMJJJASOND JEMAMI	1962 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36
H	Н	Begin S	Material X5 (150 Tests (150 Material	X5019 (75 Tests Mai. AVG			2	T uis	Mate Phas Phas	Mate Phase A [24	Mat	c	2	H

Figure 2 (Cont'd)

ID J F IMIA IMIJIJIA ISTOINID	23 24 25 26 27 28 29 30 31 32 33 34 35 36			DJFMAM	124 25 26 27 28 29 30 31 32 33 34 35 36
JIF IMIAIMIJJIAISTOIN	20 21 22	Ape Tests	Production Lots (80 Tests)	J F M A M J J A S O N	1963 3 14 5 16 17 18 19 20 21 22 23 24
JIF M A M J J A S I O I N I D	1 2 3 4 5 6 7 8 9 10 11 12	Material X5026 (28 Tests) Material X5019 [27 Tests) Material AVCOAT II (9 Tests) Adhesive Bonds (40 Tests) Material X5026 (32 Tests) Material X5026 (32 Tests) Material X5019 (13 Tests) Material X5019 (13 Tests) Material AVCOAT II (11 Tests) Adhesive Bonds (18 Tests) Adhesive Bonds (18 Tests)	Å	JIF [M] A [M] J A S O N D	1 2 3 4 5 6 7 8 9 10 11 12

Figure 2 (Cont'd)

JAISTOINID JIFIMIAIMIJIJIAISIOINID JIFIMIAIMIJ
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36
Degin Testing for the Measurement of Transmittance, Reflectance, and Emissivity Including Char Tests
Material X5026 360 Tests)
Material X5019 108 Tests)
Material Avcoat II (108 Tests)
2nd Generation(120Tests)
Production Lots (60 Tests)
JEMAMUJJASONDJEMAMUJJASONDJEMAMJJASOND
Begin Testing Materials Response to Combined Radiative and Convective Heating on the Blunt Face
Material - X5026 (41 Tests)
Material - X5019
Adhesive Bonds
(19 Tests)
Znd Generation eration (11 Tests)
JASONDJEMAMJJJASONDJJAMJ
1962

Figure 2 (Cont'd)

Figure 2 (Concl'd)



1.3 MATERIALS PROPERTIES TESTS (See Figure 3)

1.3.1 Laboratory Determination of Thermal Properties

The thermal properties (k versus T, c_p versus T, heat of combustion) of proposed Apollo heat shield materials shall be measured experimentally. These tests shall obtain the physical properties necessary for the evaluation of the heat equations.

Steady-state values of thermal conductively, k, as a function of temperature shall be measured using a guarded hot plate apparatus. The specific heat, cp, shall be measured as a function of temperature, using method of mixtures apparatus. The heat of combustion shall be determined by Parr Bomb calorimeter experiments. Where applicable, each of the above three experiments shall be performed according to ASTM and/or MIL SPEC procedure. The specific heat and thermal conductivity shall be measured transiently using the Trans-Prop apparatus. Experiments are to be performed on each material in the virgin and fully charred states.

1.3.1.1 The testing began in May 1962 and shall continue as dictated by design requirements.

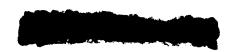
a. Test description

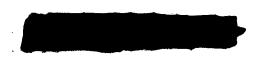
The following list the number of specimens to be tested in each test for (1) thermal properties of the virgin material, (2) char properties, and low temperature (-260°F) evaluation of thermal properties.

It assumes that low temperature evaluations of charred material will not be needed.

1) Test specimens to determine properties of virgin materials

Material	Property	Number of Specimens
Avcoat 5026	Thermal Conductivity	81
	Specific Heat	114
	Heat of Combustion	80
Avcoat II	Thermal Conductivity	12
	Specific Heat	12
	Heat of Combustion	10

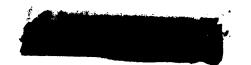




JF MAMININIA STOINID	[22 23 24 25 26 27 28 29 30 31 32 33 34 35 36		DINIOISIA DINIA MINIO	19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36
J F M A M J J A S O N D	13 14 15 16 17 18 19 20 21 22 23 24	n Lot Testing* (160 Tests)	O N O S A D O N O N O N O N O N O N O N O N O N O	13 14 15 16 17 18 19 20 21 22 23 24
IAISIOINID	1 2 3 4 5 5 6 7 8 9 10 11 12	Material Mat	ASOND	1 2 3 4 5 6 7 8 9 10 11 12 1

Figure 3 MATERIALS QUALIFICATION -- THERMAL PROPERTIES

Figure 3 (Concl'd)



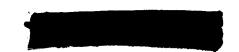
Material	Property	Number of Specimens
Avcoat X5019	Thermal Conductivity	12
	Specific Heat	12
	Heat of Combustion	10
Second Generation	Thermal Conductivity	50
	Specific Heat	50
	Heat of Combustion	25
Production	Thermal Conductivity	80
	Specific Heat	80
	Heat of Combustion	40

2) Evaluation of char properties

Material	Property	Number of Specimens
Avcoat X5026	Thermal Conductivity	132
	Specific Heat	1 32
	Heat of Combustion	65
Avcoat II	Thermal Conductivity	12
	Specific Heat	12
	Heat of Combustion	12
Avcoat X5019	Thermal Conductivity	12
,	Specific Heat	12
	Heat of Combustion	12
Second Generation	Thermal Conductivity	50
	Specific Heat	50
Production Lots	Thermal Conductivity	80
1 1 oddovion 1000	Specific Heat	80

3) Low temperature evaluation of thermal properties

Material	Property	Number of Specimen:			
Avcoat X5026	Thermal Conductivity Specific Heat	18 36			
Avcoat II	Thermal Conductivity	3			





				1962					
Schedule		May	June	July	Aug	Sep	Oct	Nov	Dec
Avcoat X5026	k	14	14	14	14	14	7	4	
	c _p	20	20	20	20	20	10	4	
	Н _с	14	14	14	14	14	7	3	
Avcoat II	k		3	3	3	2	1		
	c _p		3	3	3	2	1		
	Н _с		3	3	3	2	1		
Avcoat X5019	k		3	3	3	2	1		
	c _p		3	3	3	2	1		
	Н _с		3	3	3	2	1		
Avcoat X5026	k	15	25	2 5	25	25	10	7	
Char	с _р	15	25	25	25	25	10	7	
	Н _с	6	14	14	14	10	4	3	
Avcoat X5019	k		3	3	3	2	1		
Char	c _p		3	3	3	2	1		
	Н _с		3	3	3	2	1		

Avcoat II Char

(Same as Avcoat 5019 Char)



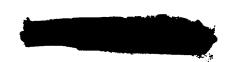
-:	- 18 A

		1	962			196	3		
Schedule		Nov	Dec	Jan	Feb	Mar	Apr	May	June
Production Lots	k	2	4	4	4	4	4	4	4
	c _p	2	4	4	4	4	4	4	4
				196	3			1964	
		July	Aug	Sep	Oct	Nov	Dec	Jan	Feb
Production Lots	k	4	4	4	4	4	4	4	4
	сp	4	4	4	4	4	4	4	4
				1	964				
		Mar	Apr	May		July	Aug	Sep	
Production Lots	k	4	4	4	4	2			
<u>.</u>	c _p	4	4	4	4	2			

1.3.2 Materials Qualification--Mechanical Property Tests

This task covers the mechanical property testing of all heat shield materials through the phases of screening, development, and qualification, and includes the following:

- a. The complete evaluation of a reference formulation of Avco X5026 through preproduction and qualification.
- b. The mechanical screening of eight other formulations of Avcoat X5026 for the selection of best candidates for pre-production tests.
- c. The pre-production and qualification testing of the optimized version of Avcoat X5026.
- d. The pre-production and qualification testing of cast Avcoat II.
- e. The pre-production and qualification testing of Avcoat 5019.
- f. The mechanical testing of bonds and fasteners.
- g. Specialized tests such as thermal and mechanical cycling tests and effect of outgassing in vacua on mechanical properties.





- h. Continuous screening of product improvement materials.
- i. Pre-production and qualification testing of product improvement materials.

Scheduling provides for evaluation of the reference X5026 formulation for preliminary design properties plus continuing evaluation of additional formulation variations to lead to an optimum formulation choice for production. In addition, simultaneous testing shall continue on two materials for use on the conical vehicle section.

1.3.2.1 Material -- Avcoat X5026

1.3.2.1.1 Reference formulation of Avcoat X5026--screening tests

Avco shall select a reference formulation of Avcoat X5026 which shall be processed through the standard materials selection procedure. The screening step provides initial data on this reference material (tile size $12 \times 12 \times 1$ inches).

a) Specimen orientation parallel to bond line

	Type of Test	Test Conditions	Number of Tests
<u>1</u>	Tensile	3T x 5n x 1	15
<u>2</u>	Thermal Expansion	5n	5
3	Moisture Expansion	5n	5

b) Specimen orientation perpendicular to bond line

	Type of Test	Test Conditions	Number of Tests
1	Tensile	lT x 5n x l (Ultimate only at RT)	5
2	Thermal Expansion	5 n	5
3	Moisture Expansion	5n	
		Per Batch	40



T = -100°F, RT, 350°F.

 $\dot{\epsilon} = 0.005$

c) Test condition symbols (also apply to all subsequent pages) are as follows:

T = Test temperatures

n = Number of tests

 $\dot{\epsilon}$ = strain rate

 ϵ = strain level

 σ = stress level

T_c = cure temperature

cure time

1.3.2.1.2 Optimized formulation of Avcoat X5026 -- Pre-screening tests

Eight additional variations of Avcoat X5026 shall be evaluated in pre-screening to provide sufficient data for comparative evaluation in the materials selection procedure (tile size $12 \times 12 \times 1$ inches).

Type of Test	Test Conditions	Number of Tests
Tensile	Standard atmosphere, parallel to bond line, 3T x 6n x l Standard atmosphere perpendicular to bond	18
	line, lT x 3n x l	3
Thermal Expansion	Standard atmosphere parallel to bond line, 12n	12
	Standard atmosphere perpendicular to bond line, 6n	6
Moisture Expansion	Standard atmosphere parallel to bond line, 12n	12
	Standard atmosphere perpendicular to bond line 6n -55-	6



Metallography

T = -100°F, RT, 350°F,

 $\dot{\epsilon} = 0.005.$

Per Formulation

81

24

1.3.2.1.3 Optimum formulation of Avcoat X5026 - Screening tests

Three formulations shall be selected from the pre-screening evaluation for screening to provide preliminary data (tile size: $12 \times 12 \times 1$ inches).

a) Specimen orientation parallel to bond line

		Type of Test	Test Conditions	Number of Tests
	1	Tensile	3T x 5n x 1	15
	2	Thermal Expansion	5 n	5
	<u>3</u>	Moisture Expansion	5n	5
b)	Spe	cimen orientation	perpendicular to	bond line
	1	Tensile	1 T x 5n x 1	5
	2	Thermal Expansion	5n	5
	<u>3</u>	Moisture Expansion	5n	5
		T = -100°F, RT,	Per Batch 350°F	40
		$\dot{\epsilon} = 0.005$		

1.3.2.1.4 Reference formulation of Avcoat X5026--Pre-production tests

Pilot production of essentially full-size tiles of the reference formulation shall provide material for test from which design data are obtained (tile size $24 \times 30 \times 1-1/2$ inches maximum--three configurations)



a) Specimen orientation parallel to bond line

		Type of Test	Test Conditions	Number of Tests
	1	Tension	3T x 5n x 3 (2 hr/test)	45
	2	Compression	3T x 5n x 1 (2 hr/test)	45
	3	Torsion	3T x 5n x 1 (2 hr/test)	45
	4	Thermal Expansion	5n (4 hr/test)	5
	<u>5</u>	Moisture Expansion	5n (2 hr/test)	5
b)	Spe	cimen orientation	perpendicular to be	ond line
	1	Tension	lT x 5n x l (Ult. only at RT)	5
	<u>2</u>	Compression	3T x 5n x 1	15
	<u>3</u>	Thermal Expansion	5t	5
	4	Moisture Expansion	5t	5

T = -260°F, RT, 500°F

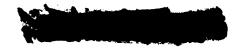
 $\dot{\epsilon} = 0.005, 0.5, 5.0 \text{ in./in./min.}$

1.3.2.1.5 Optimized formulation of Avcoat X5026 -- Qualification testing

Per Configuration

175

Qualification testing of selected production tiles is carried out for the determination of final design properties (panel size $18 \times 36 \times 1$ inches --three configurations). Refer to Tables II through VI.

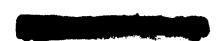


	Type of Test	Number of	Tests
1	Tension standard standard	70 15	
2	Compressive standard standard	70 15	
3	Shear (Torsion)standard	40	
4	Thermal Expansion (Ambient) (Ambient)	75 75	
<u>5</u>	Moisture Expansion (Ambient) (Ambient)	75 7 5	
<u>6</u>	Flexure (Ambient) 2-1/2 hr/test	40	
7	Fatigue (Ambient)	90	
<u>8</u>	Tensile Creep (Long)	36	
9	Tensile Relaxation (Long)	36	
<u>10</u>	Compressive Creep (Long)	36	
	Parallel to Bond Line Perpendicular to Bond Line	36 36	
11	Compressive Relaxation (Long) Parallel to Bond Line Perpendicular to Bond Line	36 36	
12	Tensile Relaxation (Very Short)	96	-
	Per Configurat	ion 952	

1.3.2.2 Material -- Avcoat II

1.3.2.2.1 Cast Avcoat II -- Pre-production testing

Pre-production testing shall include two processing modifications tests to provide design data (panel size $12 \times 12 \times 1/2$ inches).



RT cure -- Elevated temperature post-cure

	Type of Test	Test Condition	Number of Tests
1	Tension	$3T \times 5n \times 3$	45
2	Compression	3T x 5n x 1	15
<u>3</u>	Torsion	$3T \times 5n \times 1$	15
4	Thermal Expansion	5n	5
<u>5</u>	Moisture Expansion	5 n	5
		Per Mate	rial 85

T = -260°F, RT, 160°F

 $\dot{\epsilon} = 0.005, 0.05, 0.5$

1.3.2.2.2 Cast Avcoat II -- Qualification testing

Qualification testing of selected material shall provide final design data. Refer to Tables VII through X.

	Type of Test	Number of Tests
1	Tension Standard at 4	290
2	Tensile Creep	72
3	Tensile Relaxation (Long Time)	72
4	Tensile Relaxation (Short Time)	160
<u>5</u>	Compressive Standard parallel to Bond Line	210
<u>6</u>	Compressive (perpendicular to Bond Line)	210
7	Compressive Creep (Long Time)	72
8	Compressive Relaxation (Long Ti	ime) 90

	Type of Test	Number of Tests
9	Fatigue	90
10	Thermal Expansion	30
11	Moisture Expansion	30
12	Shear (Torsion) Standard	210
	Per Material	1536

1.3.2.3 Material -- Avcoat X5019

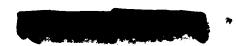
1.3.2.3.1 Avcoat X5019 -- Pre-production testing

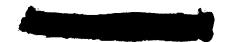
Pre-production testing for Avcoat X5019 shall be the same as for Avcoat II, paragraph 1.3.2.2.1

1.3.2.3.2 Avcoat X5019 -- Qualification testing

Qualification Testing shall provide final design data. Refer to Tables XI through XIV.

	Type of Test	Number of Tests
1	Tension Parallel (to	70
	laminations) Stand Perpendicular standard	15
<u>2</u>	Tensile Creep (Long Time)	36
3	Tensile Relaxation (Long Time)	36
4	Tensile Relaxation (Short Time)	36
<u>5</u>	Compressive Parallel Standard	70
	PerpendicularStandard	15
6	Compressive Creep (Long Time) 36
_	•	36
7	Compressive Relaxation (Long Time)	36
<u>8</u>	Torsion Parallel Ambient	40
	-60-	





	Type of Test	Number of Tests
9	Thermal Expansion Parallel Perpendicular	75 75
10	Moisture Expansion ParallelPerpendicular	75 75
11	Flexture	40
12	Fatigue	45
	Per Materi	al 847

1.3.2.4 Mechanical Fasteners and Bonding

1.3.2.4.1 Screening of mechanical fasteners

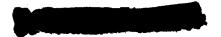
For two X5026 formulation reference and optimized, ten of the most promising available fastener designs will be mechanically screened in tension and shear at room temperature only.

	Type of Test	Test Condition	Number of Tests
1	Tensile	lT x 5n x l testing rate	5
2	Shear	1T x 5n x 1 testing rate	5
		Per Material/Per	10

1.3.2.4.2 Qualification of fasteners

As the result of screening tests of ten fasteners, two will be qualified at temperature from -260° to 1000°F for both X5026 materials.

	Type of Test	Test Condition	Number of Tests
1	Tension	$ST \times 5n$	40
2	Shear	ST x 5n	40
		Per Fastener	r 80



1.3.2.4.3 Screening of adhesives

Eight different adhesives will be screened on one substrate.

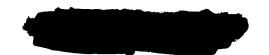
	Type of Test	Test Condition	Number of Tests
1	Tension	1T x 5n x 3 Surface Preparations	15
2	Shear	1T x 5n x 3 Surface Preparations	15
		Per Adhesive	30

1.3.2.4.4 Optimization of bond techniques and curing cycles

To determine the maximum efficiency of the three adhesives selected in the previous section, various curing cycles will be investigated to include three cure temperatures, and three cure times on one surface preparation. Surface preparations have been previously selected. This will be performed for two materials, Avcoat X5026 and Avcoat II or Avcoat X5019.

	Type of Test	Test Conditions	Number of Tests
1	Tension	$3T \times 5n \times 3$ $3T_C \times 3t_C \times 1$ substrate	405
2	Shear	3T x 5n x 3 Adhesives 3T _C x 3t _c x 1 Substrate	405
		Per Material	810

T = -260°F, RT, 350°F.



1.3.2.4.5 Qualification of adhesives

Qualification tests of adhesive bonds will be performed over the temperature range from -260° to 1000°F.

	Type of Test	Test Condition	Number of Test
1	Tension	8T x 5n x 1 Adhesive x 1 Substrate	40
2	Shear	8T x 5n x 1 Adhesive x 1 Substrate	40
		Per Adhesive	80

The effect of thermal cycling on the bond will be determined by programming the desired temperature-time history into the substrate material using rapid heating rate techniques. The bond line will be examined by nondestructive techniques, then evaluated in shear at RT destructively.

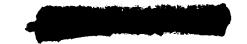
Tests will be performed to establish order-of-magnitude heat shield and the metallic substrate.

Type of Test	Test Condition	Number of Test
Tensile Creep	$-3T \times 3\sigma \times 1$ Adhesive $\times 1$ Substrate	9
Tensile	-3T c 3€ x l Adhesive c l Substrate	9
	Per Material	18

1.3.2.5 Special Tests

1.3.2.5.1 Vacuum testing feasibility study -- Testing

This covers the testing support of a subcontract study to be conducted by the National Research Corporation's Research Division on the equipment and material problems involved in simulation of altitude-temperature conditions during mechanical property testing. It includes the determination of vacuum equipment limitations, the deterioration of properties with outgassing, as





well as the outgassing characteristics of the pertinent shield material under simulated temperature-pressure conditions. Optimization of in vacua test techniques and time-pressure-temperature cycling will be a natural outgrowth of the task.

1.3.2.5.1.1 Simulated testing

The vacuum chamber facilities of NRC's Research Division shall be used for this program because of NRC's experience, facilities, delivery capability, and close proximity to Avco RAD.

Avcoat II, X5019, and one formulation of X5026 shall be evaluated for outgassing and half-life characteristics at different temperature levels. The volume and outgassing sources of the NRC chamber used in these tests shall approximate as closely as possible those anticipated in a postulated custom-designed chamber, that is adaptable to a universal test machine and incorporates the necessary mechanical and instrumentation features.

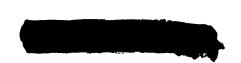
Evaluation of material degradation with time shall be made by weight loss and limited mechanical testing after exposures.

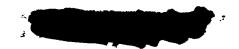
Comparative evaluation of time-pressure-temperature outgassing curves shall be made to determine pressure limitations of the equipment as well as aid in optimizing thermal cycles.

A comparison of property test results conducted in both (a) vacua and (b) environmental chambers under similar time-temperature conditions will aid in resolving:

- $\frac{1}{\text{tests}}$. The importance of pressure simulation for future
- The degree of correlation that can be achieved between the two types of test environment.
- 1.3.2.5.1.2 Preparation of material and development of testing techniques

Standard-size test specimens of the pre-selected formulations shall be prepared and tested as individual and multiple bar loadings in the chamber. The anticipated fragility of degraded specimens will require the use of simple bar designs and the development of strain-measuring techniques for charred or partially charred materials.





1.3.2.5.2 Avcoat X5026 thermal and mechanical cycling tests in tension and compression

The stress-strain curves obtained under equilibrium conditions at various levels: e.g., 900°, 600°, 300°, and 77°F, shall be used to determine the maximum strain levels which shall be achieved in the mechanical cycling.

The following procedure shall be employed to determine the effect of low cycle tension and compression fatigue on the behavior of Avco X5026.

- a) The specimen shall be brought to temperature at the maximum possible rate and stabilized at the desired level, then strained to one-third of the yield stress (as previously determined). It shall be held at this constant strain and the relaxation characteristics determined for a pre-selected length of time. After this time, the specimen shall be unloaded and the amount of permanent deformation determined.
- b) The temperature of the specimen shall then be cooled to the next level and stabilized; loaded to one-third of the yield strain (as determined for this temperature level) and held for the same length of time as in (a) for the relaxation curve. The specimen shall then be unloaded as before, noting the amount of permanent deformation, if any.
- c) The same procedure shall be followed down to 77°F, at which temperature the specimen shall be strained to failure upon completion of the cycling.
- d) The same procedure shall be followed on other specimens, loading them to two-thirds of the yield strain and at the yield strain.
- e) The same procedure in its entirety shall be followed in compression.

1.3.2.6 Product Improvement Materials

The procedures and tests for screening, pre-production, and qualifications testing for product improvement materials shall be the same as presented in paragraphs 1.3.2.2 through 1.3.2.4.

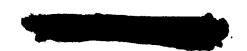




TABLE II

MECHANICAL PROPERTIES TO BE DETERMINED FROM EACH TYPE OF TEST

Tensile:

Elastic modulus (E_t), proportional limit (F_{tp}), yield stress (F_{ty}), ultimate stress (F_{tu}) and strain (ϵ_t), Poisson's Ratio (μ), and stress/strain curve.

Compression:

Elastic modulus (E_c), proportional limit (F_{cp}), yield stress (F_{cy}), ultimate stress (F_{cu}) and strain (ϵ_c), Poisson's Ratio (μ), and stress/strain curve.

Torsion:

Modulus of rigidity (G), yield stress (F_{sy}), ultimate shear stress (F_{su}), torque (T), and torque versus twist angle curve.

Tensile Creep:

Minimum creep rate $\left(\frac{d \epsilon_t}{d_{t_{min}}}\right)$, creep rupture stress, and strain/time curve.

Compressive Creep:

Minimum creep rate $\left(\frac{d \epsilon_{c}}{d_{t_{min}}}\right)$, and strain/time curve.

Tensile Relaxation:

Relaxation rate $\left(\frac{d\sigma_t}{d_t}\right)$, relaxation time (t_{tr}), residual stress, and stress/strain curve.

Compression Relaxation:

Relaxation rate $\left(\frac{d\sigma_c}{d_t}\right)$, relaxation time (t_{cr}), residual stress, and stress/strain curve.

Fatigue:

S-N curves, and endurance limit (S_{ϵ}).

Thermal Expansion:

Coefficient of thermal expansion (a), transition temperature (T_g) , and strain-temperature curve.

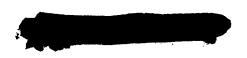




TABLE II (Concl'd)

Moisture Expansion:

Strain-time curve.

Flexure:

Proportional limit (F_{FP}), modulus of rupture [flexural strength (F_{FU})], clastic modulus (E_B), and maximum strain ($\epsilon_{F_{max}}$).

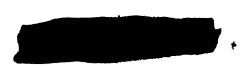




TABLE III

SPECIMENS USED FOR THE MECHANICAL EVALUATION OF AVCOAT X5026-TYPE MATERIALS

Number	Specimen	Remarks
1	Tensile	
	TS-101-2	Shoulder type; 2.13-inch reduced section tapered.
	TS-110-1	UTS only; Total length 0.875 inch or greater; Bonded to EM-01400 aluminum studs.
2	Compression	
	TS-202	3/4-inch diameter by 1-1/2 inches long.
3	Tensile Creep	
	TS-101-2	Shoulder type; 1.125-inch reduced section tapered.
4	Compressive Creep	
	TS-202	3/4-inch diameter by 1-1/2 inches long.
5	Tensile Relaxation	
	TS-101-2	Shoulder type; 1.125-inch reduced section tapered.
6	Compressive Relaxation	
	TS-202	3/4-inch diameter by 1-1/2 inches long.
7	Torsion	
	TS-404	6 inches long by 3/4-inch wide by 1/2-inch thick.
8	Flexure	Refer to ASTM-D790



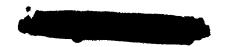


TABLE III (Concl'd)

Number	Specimen	Remarks
9	Moisture and Thermal Strain	
	TS-301-1	1/2-inch diameter by 5 inches long.
ļ _	TS-301-2	1/2-inch diameter by 4 inches long.
10	Fatigue	
	TS-407-1	Tension only; Total length = 5.00 inches.
	TS-407-2	Complete reversal; Total length = 3.75 inches.

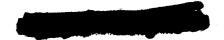


TABLE IV

MINIMUM NUMBER OF TESTS/CONDITION/CONFIGURATION FOR THE EVALUATION OF COMPRESSIVE CHARACTERISTICS OF AVCOAT X5026 (INCLUDING CREEP AND RELAXATION)

Type of	Test Temp.	Spec. Orientation		Atmo:		Justification and Remarks				
Test	°F	Orientation	0.005	0.5	5.0					
Compressive	-260 -100 RT 250 350 500 750 1000	Parallel to bond line	5 5 5 5 5 5 5	5 5 5	5 5 5	 Compressive properties versus temperature under standard atmospheric pressures in direction parallel to bond line for design use. 				
	-260 -100 RT 250 350 500 750 1000	Perpendicular to bond line	5 5 5 5 5 5			Compressive properties versus temperature under standard atmospheric pressures in direction perpendicular to bond line for design use.				
Compressive Creep (Long Time)	-260 RT 350	T bond line		ess or in Lev		 Compressive creep properties for use in storage and transportation environment control. Temperature range may be altered as required. Stress levels to be selected from standard compressive tests 				
	-260 R T 350	Perpendicular to bond line	σ ₁ 4 4 4	σ ₂ 4 4 4	σ ₃ 4 4 4 4	Same as parallel to bond line.				
Compressive Relaxation (Long Time)	-260 RT 350	Parallel to bond line	4 4 4	4 4 4	€3 4 4 4	Compressive relaxation properties for use in storage and transportation environment control. Temperature range may be altered as required. Strain levels to be selected from standard compressive tests				
	-260 RT 350	Perpendicular to bond line	4 4 4	4 4 4	€3 4 4 4	Same as parallel to bond line.				

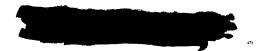


TABLE V

MINIMUM NUMBER OF TESTS/CONDITION/CONFIGURATION FOR THE EVALUATION OF TENSILE CHARACTERISTICS OF AVCOAT X5026 (INCLUDING CREEP AND RELAXATION)

Type of	Test Temp. Spec.		Std. Atmos. Test Rate				Justification and Remarks
Test	°F	Orientation	0.005	0.5	5.0	1	
Tensile	-260 -100 RT 250 350 500 750 1000	Parallel to bond line	5 5 5 5 5 5 5	5 5 5	5 5 5	1.	Tensile properties versus temperature in standard atmospheric pressures in directions parallel to bond line for design use.
	-260 -100 RT 250 350 500 750 1000	Perpendicular to bond line	5 5 5			1.	Spot checking of tensile properties at varient temperatures in standard atmosphere for the determination of any severe weaknesses in directions perpendicular to bond line.
Tensile Creep (Long Time)	-260 RT 350	Parallel to bond line		ess or Δeve σ ₂ 4 4 4		1. 2. 3.	Extent of long time tensile creep characteristics for use in storage and transportation environment control. Temperature range may be altered as required. Stress levels to be selected from standard tensile tests.
Tensile Relaxation (Long Time)	-260 RT 350	Parallel to bond line	€ ₁ 4 4 4	€2 4 4 4	€3 4 4 4	1. 2. 3.	Extent of long time tensile relaxation characteristics for use in storage, transportation, and in determining the effect of fastener pressures. Temperature range may be altered as required. Strain levels to be selected from standard tensile tests.
Tensile Relaxation (Short Time)	-260 -100 RT 250 350 500 750	Parallel to bond line	σ ₁ 4 4 4 4 4 4 4	σ ₂ 4 4 4 4 4 4	73 4 4 4 4 4 4 4 4	1. 2.	required for basic viscoelastic analyses.

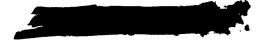


TABLE VI

MINIMUM NUMBER OF TESTS/CONDITION/CONFIGURATION FOR THE EVALUATION OF TORSION, THERMAL AND MOISTURE EXPANSION, FLEXURE, AND FATIGUE CHARACTERISTICS OF AVCOAT X5026

Type of Test	Test Temp.	Specification Orientation	Ambient	Justification and Remarks
Torsion	-260 -100 RT 250 350 500 750	Parallel to bond line	5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5	Basic shear characteristics versus temperature under standard pressures for design use.
Thermal Expansion	-260 to 1000	Parallel to bond line	75	1. At least one test per panel for determination of $T_{\mbox{\scriptsize g}}$ variations as well as α variations.
	-260 to 1000	Perpendicular to bond line	75	Same as parallel to bond line.
Moisture Expansion	100 96 50	Parallel to bond line	75	Inexpensive means of determining extent of moisture effects. If effects are excessive, additional tensile properties shall be determined as a function of moisture.
	100 96 50	Perpendicular to bond line	75	Same as parallel to bond line,
Flexure	-260 -100 RT 250 350 500 750 1000	Parallel to bond line	5 5 5 5 5 5 5	Flexure characteristics versus temperature under standard atmospheric conditions for design use. Of secondary importance; performed to determine whether any gross weaknesses occur in bending.
Fatigue	-260 -100 RT 250 350 500 750 1000	Parallel to bond line	30 30 30	Fatigue characteristics versus temperature for design use. In brittle material such as Avcoat X5026, effect of porosity and stress concentrations could be of extreme importance for failure prediction.

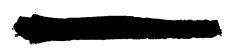




TABLE VII

SPECIMAN TYPES USED FOR THE MECHANICAL EVALUATION OF CAST AVCOAT II

Specimen	Remarks
TS-106	Tapered (0.005 inch) ASTM Type I Flat (2-inch gage length). Tensile specimens for low strain rates (0.05 and 0.5).
TS-112	Untapered ASTM Type I Flat (2-inch gage length). Tensile creep and relaxation specimens.
TS-108	Tapered (0.005 inch) Flat (1-inch gage length). Tensile specimens for high strain rate (4.0 in./in./min), fatigue, and impact.
TS-202	3/4-inch diameter by 1/4-inch thick discs. Compression, compression creep, and relaxation specimens.
TS-202	3/4-inch diameter by 1-1/2 inches long. Compression specimens (6 discs 1/4-inch thick stacked and bonded together).
TS-404	6 inches long by 3/4-inch wide by 1/2-inch thick (gage section turned to 0.505-inch diameter). Torsion specimen.
TS-405	3 inches long by 3/4-inch wide by 1/4-inch thick flexure specimens.
TS-302	5 inches long by 1/2-inch wide by 1/4-inch thick thermal and moisture expansion specimens.

TABLE VIII

MINIMUM NUMBER OF TESTS/CONDITION FOR THE EVALUATION OF THE TENSILE CHARACTERISTICS OF AVCOAT II

	ure			Justification and Remarks	 Tensile properties versus temperature under standard pressures for design use. 	2. Different specimens used for higher strain rate tests ($\epsilon = 5.0$).		 Determination of extent of long time creep characteristics for use in storage and transportation control. 	2. Temperature ranges may be altered as required.	3. Stress levels to be selected from tensile tests.		 Determination of extent of long time relaxation characteristics for use in storage and transportation control. 	2. Temperature ranges may be altered as required.	3. Strain levels to be selected from tensile tests.		 Tensile relaxation data after very short loading times are required for basic visco- elastic analyses capecially for Avcoat II. 	2. Strain levels to be selected from tensile tests.
	ressure	ted		5.0	ĸ	rv.											
	Standard Pressure	Elevated Post-Cure	Strain Rate (in. /in. /min)	0.05 0.5	رد	rv.			 _			-					
			ate min)	5.0	ν.	νo											
	12 Months	RT	Strain Rate (in. /in. /min)	0.05 0.5 5.0													
Cast			L I		<u>.</u>		-										
	essur	Elevated	Strain Rate (in./in./min)	0.05 0.5 5.0			03	4		4	£3	4	4	4	3	4 4 4 4	444
	rd P	Elevated Post-Cure	Strain n./in.	0.		N N N N	σ2	4	4	4	62	4	4	4	€2	4 4 4 4	. 4 4 4
	Standard Pressure	-		-+			٩	4	 4	4	-1	4	4	4	<u>.</u>	4444	* 4 4 4
			ain Rate in./min)	5 5.0		~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~	σ3	4	4	4	£	4	4	4	<u>2</u>	4444	444
	1 Month	RT	Strain Rate (in./in./min	05 0.5	 -		92	4	4	4	€ 2	4	4	4	£2	4 4 4 4	444
re			<u>=</u>	<u>-</u>			6	4	4	4	<u>.</u>	4	4	4	<u>.</u>	4444	444
fanufactu			Test Temp.		-260 -35 40	60 RT 160 350		-260 -35 40	8T 140	350		-260 -35 40 60	RT 160	350		-260 -35 40 60	RT 160 350
Method of Manufacture	Aging Cycle	Cure or Post-Cure	Type of	Test	Tensile			Tensile Creep				Tensile Relaxation (Long Time)				Tensile Relaxation (Short Time)	

TABLE IX

MINIMUM NUMBER OF TESTS/CONDITION FOR EVALUATION OF THE COMPRESSIVE CHARACTERISTICS OF AVCOAT II

	Justification and Remarks				Justification and Remarks	 Compressive properties versus temperature under standard pressures for design use, perpen- dicular to bond line. 	Parallel to bond line		1. Determination of extent of long time creep	characteristics for use in storage and transportation control. 2. Temperature ranges may be altered as required. 3. Stress levels to be selected from standard compressive tests.	1. Determination of extent of long time relaxation	
		ssure	ed 1re		5.0							
	1	Standard Pressure	Elevated Post-Cure		5 0.5	1,=0,=					ļ Ļ	
		Standa			0.05		<u> </u>					
	ļ		E4	Rate /rnin)	5 5.0						-	
		12 Months	RT		0.5							
\vdash	+	-			0 0.05				_		+-	
		ssure	ated	Strain Rate (in./in./min)	5 5.0		-		2 93	4 4 4	-	
		Standard Pressure	Elevated Post-Cure	Strain Rate in, /in, /mir	0.5	w w w w w w w		~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~	Ь	4 4 4	-	
		tanda			0 0.05	www.www	-	w w w w w w	٠ م	-	₩	
		- 1		ain Rate in./min)	5 5.0	 	-		93		Ť	
		1 Month	RT		5 0.5		-	~~~~~~~~~	82	4 4	6 2	4 4
-	\bot			Str.	0.05		-		ь-	4 4 4	<u></u>	4 4
	anmacture	rcle	st-Cure	Test Temp.	• Fi	-260 - 35 40 60 RT 160 350		-260 - 35 40 60 RT 160 350		-260 - 35 40 60 RT 160		-260 - 35 40 60 RT 160 350
	Method of Manuacture	Aging Cycle	Cure or Post-Cure	Type of Test		Compressive Perpendicular to Bond Line		Compressive Parallel to bond line		Compressive Creep (long time)		Compressive Relaxation (long time)

TABLE X

MINIMUM NUMBER OF TESTS/CONDITION FOR THE EVALUATION OF FATIGUE, THERMAL AND MOISTURE EXPANSION, AND SHEAR CHARACTERISTICS OF AVCOAT II

1 e e Justification and Remarks			Justification and Remarks	1. Fatigue characteristics versus temperature for design use.			1. At least one test/panel for the determination of T_g as well as α	 Inexpensive means of determining the extent of moisture effects. If results show excessive effects, additional tensile properties shall be determined as a function of moisture. 	 Basic shear characteristics versus tem- perature under standard pressures for design 	nse.	
	12 Months	Elevated Post-Cure			•		u)				
	121	RT									
	4 Months	Elevated Post-Cure					W				
	4	RT					ru				
Cast		d .e	, a						te 1)	၁	տատատատ
		Elevated Post-Cure		15	15	15	ī	տտտ	Twist Rate (rad/min)	В	
	1 Month									٧	տտտտտտտ
	1 1								ate n)	υ	տատատատ
		RT		15	15	15	ιń	~ ~ ~	Twist Rate (rad/min)	В	មាមមាមមាម មា
								 		٧	ναναναν
Method of Manufacture	Aging Cycle	e or Cure	Test Temp.	-260	40 RT	350	-260 -35 40 60 RT 160	Humidity percent 100 96 50	Test Temp.	ិ៍	-260 -35 40 60 RT 160 350
Method of Manufactur	Aging	Cure or Post-Cure	Type of Test	Fatigue			Thermal Expansion	Moi sture Expansion			Shear (Torsion)

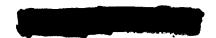


TABLE XI

SPECIMENS USED FOR THE MECHANICAL EVALUATION OF AVCOAT X5019

Number	Specimen	Remarks
1	Tensile	
	TS-107-1	For pre-flight evaluation of material samples from vehicles (thickness <0.500 mg)
	TS-104-1	Threaded; 1.25-inch reduced section.
	TS-104-2	UTS perpendicular to laminations; total length 1.38 inches.
2	Compression	
	TS-202	3/4-inch diameter by 1-1/2 inches long.
3	Shear	
	TS-402	For shear strength of laminates.
4	Tensile Creep	
	TS-104-1	Threaded; 1.25-inch reduced section.
5	Compressive Creep	
	TS-202	3/4-inch diameter by 1-1/2 inches long.
6	Tensile Relaxation	
	TS-104-1	Threaded; 1.25-inch reduced section.
7	Compressive Relaxation	
	TS-202	3/4-inch diameter by 1-1/2 inches long.
8	Torsion	
	TS-104	6 inches long by 3/4-inch wide by 1/2 inch thick.

TABLE XI (Concl'd)

Number	Specimen	Remarks						
9	Flexure	Refer to ASTM-D790.						
10	Moisture and Thermal Strain							
	TS-301-1	1/2-inch diameter by 5 inches long.						
11	Fatigue							
	TS-407-1	Tension only; 5.00 inches total length.						
	TS-407-2	Complete reversal; 3.75 inches total length						

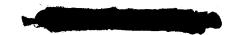


TABLE XII

MINIMUM NUMBER OF TESTS/CONDITION/CONFIGURATION FOR THE EVALUATION OF TENSILE CHARACTERISTICS OF AVCOAT X5019 (INCLUDING CREEP AND RELAXATION)

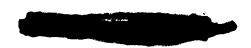
Type of Test	Test Temp.	Spec. Orientation		Atmo		Justification and Remarks
lest	°F	Orientation	0.005	0.5	5.0	
Tensile	-200 -100 RT 150 200 260 400 500	Parallel to laminations	5 5 5 5 5 5 5	5 5 5	5 5	Tensile properties versus temperature in standard atmos- pheric pressures in directions parallel to laminations for design use.
	-200 -100 RT 150 200 260 400 500	Perpendicular to laminations	5 5 5			Spot check of tensile properties at variant temperatures in standard atmosphere for the determination of any severe weaknesses in directions perpendicular to laminations.
Tensile Creep (Long Time)	-200 RT 200	Parallel to laminations		σ ₂ 4 4		 Extent of long time tensile creep characteristics for use in storage and transportation environment control. Temperature range may be altered as required. Strain levels to be selected from standard tensile tests.
Tensile Relaxation (Long Time)	-200 RT 200	Parallel to laminations	ε ₁ 4 4 4	€ 2 4 4 4	4 4 4	 Extent of long time tensile relaxation characteristics for use in storage, transportation, and in determining the effect of fastener pressures. Temperature range may be altered as required. Strain levels to be selected from standard tensile tests.
Tensile Relaxation (Short Time)	-200 RT 200	Parallel to laminations	σ ₁ 4 4 4	σ ₂ 4 4 4	σ ₃ 4 4 4	Tensile relaxation after very short loading times are required for basic viscoelastic analyses. Strain rates to be selected from standard tensile tests.



TABLE XIII

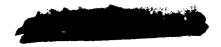
MINIMUM NUMBER OF TESTS/CONDITION/CONFIGURATION FOR THE EVALUATION OF COMPRESSIVE CHARACTERISTICS OF AVCOAT X5019

Type of Test	Test Temp.	Spec. Orientation		Atmor			Justification and Remarks
Compressive	-200 -100 RT 150 200 260 400 500	Parallel to laminations	5 5 5 5 5 5 5	5 5	5 5 5	1.	Compressive properties versus temperature under standard atmospheric pressures in directions parallel to laminations for design use.
	-200 -100 RT 150 200 260 400 500	Perpendicular to laminations	5 5 5			1.	Compressive properties versus temperature under standard atmospheric pressures in directions perpendicular to laminations for design use.
Compressive Creep (Long Time)	-200 RT 200	Parallel to laminations		ress or in Lev σ ₂ 4 4 4		1. 2. 3.	Compressive creep properties for use in storage and transportation environment control. Temperature range may be altered as required. Strain levels to be selected from standard compressive tests.
	-200 RT 200	Perpendicular to laminations	σ ₁ 4 4 4	σ ₂ 4 4 4	σ ₃ 4 4 4		Same as parallel to laminations.
Compressive Relaxation (Long Time)	-200 RT 200	Parallel to laminations	ε ₁ 4 4 4	€ ₂	€3 4 4 4	1. 2. 3.	Compressive relaxation properties for use in storage and transportation environment control. Temperature range may be altered as required. Strain levels to be selected from standard compressive tests.
	-200 RT 200	Perpendicular to laminations	€ ₁ 4 4 4	€2 4 4 4	€3 4 4 4		Same as parallel to laminations.





NUMBER OF TESTS/CONDITION/CONFIGURATION FOR THE EVALUATION OF TORSION, THERMAL AND MOISTURE EXPANSION, FLEXURE, AND FATIGUE CHARACTERISTICS OF AVCOAT X5019	Justification and Remarks	 Basic shear characteristics versus temperature under standard pressures for design use. 	1. At least one test per panel for determination of $T_{\tilde{g}}$ variations as well as α variations. Same as parallel to laminations.	1. Inexpensive means of determining extent of moisture effects. If effects are excessive, additional tensile properties shall be determined as a function of moisture.	Same as parallel to laminations.	 Flexure characteristics versus temperature under standard atmospheric conditions for design use. Of secondary importance; performed to determine whether any gross weaknesses occur in bending. 	1. Fatigue characteristics versus temperature for design use. In brittle material such as Avcoat X5026, effect of porosity and stress concentrations could be of extreme importance for failure predictions.
CONFIGURA FLEXURE,	Ambient	ក្រសួលស្នា	75	75	75	សសហសសសស	15 15 15
STS/CONDITION/(RE EXPANSION, 1	Spec. Orientation	Parallel to laminations	Parallel to laminations Perpendicular to laminations	Parallel to laminations	Perpendicular to laminations	Parallel to laminations	Parallel to laminations
R OF TES MOISTUI	Test Temp.	-200 -100 RT 150 200 260 400 500	-200 to 500 -200 to	500 100 96 50	100 96 50	-200 -100 RT 150 200 260 400 500	-200 -100 RT 150 200 260 260 400
NUMBE	Type of Test	Torsion	Therral Expansion	Moisture Expansion		Flexure	Fatigue



1.4 STRUCTURAL TESTS (See Figure 4.)

1.4.1 Composite Beam and Panel Tests

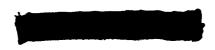
Avco shall conduct structural development tests of composite beams and panels subjected to heating and loading conditions (refer to Table XV). Typical heat-shield specimens shall be subjected to hot soak and cycling conditions from 1000°F to room temperature, and transient temperature conditions representative of ascent and re-entry environments. Temperature soak and cycling shall be conducted in a heated chamber. Transient temperature shall be obtained by infrared quartz lamps. Test specimens shall consist of single ablator tiles, composite beams, composite panels, and lapped tiles mounted on a substructure. These tests shall substantiate strength of the tile design under conbined loading, and the data shall be used to substantiate mathematical analyses used for design. Composite panels and lapped tiles mounted on the substructure shall be tested at soak conditions of 200; 400, and 600°F, as well as under transient temperature conditions with a normal pressure load representing air loads. Additional tests will substantiate strength of the tile design under combined loading effects.

1.4.2 Mechanical Fastener Tests

Avco shall test various mechanical fasteners which are under consideration for tile attachment design to evaluate tensile and shear strengths over the complete temperature range (refer to Table XV). Further shear and tensile tests shall be made of the fastener selected for final design to establish guaranteed design properties. Tests shall be conducted in a temperature-controlled chamber which is mounted on a universal testing machine.

1.4.3 Cold Soak Ablator and Composite Panel Tests

Avco shall conduct structural development tests of ablator and composite tiles in a chamber providing cold temperature soak and cycling. Specimens shall consist of ablator tiles, composite beams, composite panels, and lapped tiles mounted on a substructure. Indication of heat-shield failure and measurements of temperature gradients and substructure strain shall be obtained to indicate gross thermal stress effects, and to substantiate the mathematical analyses used in design. Additional tests of composite panels and lapped tile panels shall be subjected to cold soak and cycling and uniform pressure loading representative of aerodynamic load. These tests shall substantiate the strength of the tile design under combined environments.





1.4.4 Acoustic Tests

Avco shall test composite panels consisting of a honeycomb substructure under acoustic environment. Accelerometers shall be used to measure response frequency and deflections. These tests will indicate fatigue and fastener stress concentration problems during critical acoustic environment.

1.4.5 Mechanical Vibration Tests

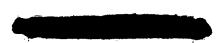
Avco shall perform mechanical vibration tests of a composite panel under critical design vibration and shock environments. Six types of vibration tests shall be performed: (a) resonance survey to determine natural frequencies of the panel, (b) sinusoidal vibration as defined by specifications, (c) random power spectral density as defined by specifications, (d) shock loads as defined by specifications, (e) combined sinusoidal and random vibration at room temperature, and (f) combined sinusoidal and random vibration at extreme temperature environments. These tests will indicate fatigue and fastener stress concentration problems by imposing critical environments to typical heat-shield specimens.

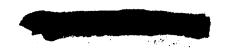
1.4.6 Structural Evaluation of Turbulent Pipe Tests

Avco shall test pipes of heat-shield material in the Avco 10-megawatt arc facility to measure thermal gradients and heat-shield stresses produced by re-entry heating. The data shall be used with a mathematical analysis of the pipe to estimate high temperature mechanical properties to be used in the design.

1.4.7 Structural Verification Tests

After final tile design is complete and heat shields are available from the production process, Avco shall perform verification tests of three typical sections of composite heat shield. To verify the heat-shield capabilities, the three portions of the vehicle shall be subjected to the critical design environments as shown in Table XVI.





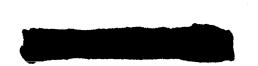
A S O N D O O F M A M D
961
AOO. Test Durat
Indicate Gross Thermal Stress effects
A (12) A Substantiate Analysis
A 6 A Substantiate Strength
Cold Soak Beam and Panel Tests
19 A Indicate Gross Therma Stress Effects.
A 6 A Substantiate Analysis.
A 6 A Substantiate Strength
Mechanical Fastener Tests
200 Evaluate Strengths of Fasteners Considered for Design
A00 Establish Charanteed Properties of Fasteners.
Turbulent Tube Tests
Δ9 Evaluate E and α for 3 Materials at High Temperatures.
Δ(3)Δ Establish Final Heat Shield E and αat High Temperatures
Acoustic Tests
A(1) Demonstrate Strength capability where Subjected to Acoustic environments.
Vibration Shock Tests
MID Simulation of Tile Response to Vibration and Shock
(
A VETINGATION OF ALL SECTION OF ALL
Crew Compartment Proof Test
}
Contai Section Floring Conical Heat Shield Strength.
JASOND JIFIMIA MIJJA SICINIO GIT MIA IN 1964
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36

Figure 4 STRUCTURAL TESTING

TABLE XV
STRUCTURAL DEVELOPMENT TESTS

Data Analysis 1 Dec 1 July 1 July 1 Dec 1 0 ct 1 July Complete 1 July l Sept l Nov 1 July 1 July Nov 1 1 May 1 Sep 1 May 2 Sep 1 July 1 May Start 12 Thermocouples 4 Biaxial
Strain Gages 6
Deflection Gages
Double Each
Item in (a) 12 Thermocouples 4 Biaxial
Strain Gages 6
Deflection Gages
Double Each
Item in (a) Conductive Grid Conductive Grid Conductive Grid Conductive Grid 12 Thermocouples BiAxial
Strain Gages 6
Deflection Gages
Double Each
Item in (a) 12 Thermocouples 4 Biaxial Strain Gages 6 Deflection Gages 10 Double Each Item in (a) Conductive Grid Instrumentation Heat Chamber a. Heat Chamber c. Heat Chamber c. Heat Chamber d. Quartz Lamps b. Quartz Lamps b. Quartz Lamps c. Quartz Lamps d. Quartz Lamps d. Quartz Lamps d. Qu ė Radiant Duartz Lamps, and Pressure Chamber Duartz Lamps, and Pressure Chamber Champs, and Pressure Chamber a. 4x4x4
Cold Chamber b
b. 4x4x4
Cold Chamber c
cold Chamber d c. 4x4x4
Cold Chamber
d. 4x4x4
Cold Chamber Heat Chamber and Pressure Chamber Heat Chamber and Pressure Chamber Chamber Chamber Chamber Heat Chamber Heat Chamber Quartz Lamps Facility ė مُ ۇن ئىنى و بن بن . . غية 12x12x1 1/2 12x12x3 Same as 5oth above 12x12x. 12x4x1 1/2 12x12x1 1/2 24x12x1 1/2 12x12x1 12x4x1 1/2 12x12x1 1/2 24x12x1 1/2 12x12x1 12x4x1 1/2 12x12x1 1/2 24x12x1 1/2 Specimen Size Same as (a) above Same as Same as:
(a) above
Same as:
(a) above Same as
(a) above
Same as
(a) above مَ يَ ن ن ن ئم ن ۇ ئا ئا خ ن غ نه ۇن ئى Number of Specimens 3 10 3 2 2 2 2 m m 2 2 2 2 . . e e 4004 غ. نه ف 🖡 . . ن ن ن <u>ن</u> ن ن ن ن ن ن Transient Temperatures
a. Ablator Tiles
c. Composite Panel
d. Lapped Tile Fanel Hot Soak and cycling (1000°F to RT)

a. Ablator Tiles
b. Composite Beans
c. Composite Panels
d. Lapped Tile Panels
on Substructure Transient Temperature Uniform Pressure Load Cold Soak and cycling (-286' Fto RT)
a. Ablator Tilen
b. Composite Beam
c. Composite Panel
d. Lapped Tiles on
Substructure Test Conditions Uniform Pressure Load Hot Soak and cycling (1000° to TR) a. Composite Panel b. Lapped Tile Panel Transient Temperature a. Composite Panel b. Lapped Tile Panels Hot Soak at 200°, 400°, 600°F (15 psi)
a. Composite Panel
b. Lapped Tile-Panel a. Composite Panel b. Lapped Tile Panel (15 psi) Indicate Gross Thermal Stress Effects Indicate Grous Thermal Stress Effects Substantiate Strength Substantiate Analysis Test Objectives Composite Beam and Panel Heat and Load Tests Cold Soak Beam and Panel Tests Test Tile



								1962	
Test Title	Test Objectives	Test Conditions	Number of Specimens	Specimen Size inches	Facility feet	Instrumentation	Start	Complete	Data Analysis
	Substantiate Analysis	Cold Soak and cycling (-260°F to RT) a. Composite Panel b. Lapped Ties On Substructure	e e	a. 12x12x1 1/2 12x12x3 b. Same as both above	a. 4x4x4 Cold Chamber b. 4x4x4 Cold Chamber	a. 12 Thermocouples 4 Biaxial Strain Cages 6 Deflection Cages b. Double Each Item in (a)	1 July	d. Ce	1 Oét
<u>.</u>	Substantiate Strength	Cold Soak and cycling (-260'F to RT) a. Composite Panel b. Lapped Tile-Panel	ന ന ക് ക്	a. 12x12x1 1/2 12x12x3 b. Same as both above	a. Cold Chamber and Pressure Chamber b. Gold Chamber and Pressure Chamber	a. Same as (a) above	l Sep	1 Nov	1 Dec
Mechanical Fastener Tests	Evaluate Strengths of Fasteners Considered For Design	Tensile Test From -260° to 600° F	500	To be determined	Tensile Machine, Cold Chamber Heating Chamber	Load Transducer and 1 June Thermocouples Same as above	1 June	1 July	1 July 1 July
		Shear Test From -260°F to 600°F	200	To be determined	Same as above	-		ĵ	Î
	Establish Guaranteed Properties of Fastener	Tensile Test From -260° to 600° F	200	To be determined	Same as above	Same as above	9 Sep	1 Oct	1 Oct
		Shear Test From -260° to 600° F	200	To be determined	Same as above	Same as above	9 Sep	1 Oct	1 Oct
Turbulent Tube Test	Evaluate E and For Three Heat Shield Materials at High Temperature	Enthalpy = H/RT _o = 150 q = 500 Btu/ft ² sec Turbulent Flow	o-	15 Tube, 21/2 OD	10-megawatt Arc	5 Thermocou- ples 6 Strain Gages	1 June	1 July	15 July
	Establish Final Heat Shield E and at High Temperatures	Enthalpy = H/RT ₀ = 150 q = 500 Btu/ft ² sec Turbulent Flow	e.	Same as above	Same as above	Same as above	15 July	1 Sep	1 Oct
Acoustic Tests	Demonstrate strength capability when sub- jected to acoustic environments	150 db 4.7 to 9.4 cps 153 db 9.4 to 18.8 cps 156 db 10.8 to 37.5 cps 156 db 37.5 to 75.0 cps 1515 db 75.0 to 150 cps 151 db 150 to 300 cps 142 db 600 to 1200 133 db 1200 to 2400 cps 133 db 2400 to 4800 cps 120 db 4800 to 9600 cps	-	24x36x0, 5 Honeycomb Panel with 81x12x12x1	WADC Dayton or comparable facility	6 Accelerometers	8n V	1.8ep	30 Sep
Vibration Shock Tests	Indicate fatigue and fastener stress concentration problems tile responses to vibration and shock.	1. Resonance Survey	-	24x36x, 50 Honeycomb Panel with six 12x12x1 Heat Shield Tiles	Avco RAD C-182, Calidyne Shaker, (15, 00 lb)	15 Accelerometers	1 June	15 June	30 Sep
				18x12x0,50 Panel with 1-12x0,12x1 and One 12x6x1 Heat Shield Tiles	Same as above	Same as above	l June	15 June	30 June

TABLE XV (Concl'd)

							1962	
Test Objectives	Test Conditions	Number of Specimens	Specimen Size inches	Facility	Instrumentation	Start	Complete	Complete Data Analysis
	2. Sinusoidal 0.6 g 5 to 20 cps 4.0 g 20 to 50 cps 20.0 g 50 to 50 cps 30.0 g 500 to 500 cps 30.0 g 200 to 500 cps 40.0 g 500 to 200 cps 5-Minute Duration at Above Lavels at Resonant Frequencies	2	Same as above	Same as above	15 accelerometers	15 June	1 July	15 July
	 Random Power Spectral Density 0, 30 g²/cps From 5 to 2000 cps 	N	Same as above	Same as above	15 accelerometers	1 July	15 July	1 Aug
	4. Shock 20 g 11 Millise conds Applied in three Mutually Perpendicular Directions	en	18x12x0.50 Panel One 12x12x1 Tile One 12x6x1 Tile	Avco RAD Shock Testing Machine	6 accelerometers	1 July	15 July	l Aug
	5. Combined Tests Random Vibration With Superimposed Sinusoidal Vibration, Limits as Specified by (2) and (3) above	7	18x36x0, 50 Panel Two 12x12x1 Heat Tiles	Avco RAD C-182, Calidyne Shaker (15,000 lb)	15 accelerometers	15 July	30 July	15 Aug
	6. Vibration Tests Conducted under Extreme Temperature Environments	1	18x12x0,50 Panul One 12x12x1 Heat Tile One 12x6x1 Heat Shield Tile	Avco RAD C-182 Calidyne Shaker (15,000 1b) and Tempera- ture Environment Chamber	6 accelerometers	15 July	30 July	15 Aug

TABLE XVI

STRUCTURAL VERIFICATION TESTS

	a Analysis	Sep 63	1 Dec 63	Apr 64
1963-64	Start Complete Data Analysis	July 63	Oct 63	Nov 63 1 Feb 64 1 1 Apr 64
	Start C.	May 63	Aug 63 C	Nov 63 1
	Instrumentation	Avco RAD Strain Gages Structural Thermocouples Test Laboratory Deflection Gages Load Transducers	Same as above	Same as above
	Facility	Avco RAD Structural Test Laboratory	Same as above	Same as above
	Specimen Size	Substructure Panel Avco RAD A Specified in Structural NAA Substructure Test Labor Design with Heat Shield Attached	Same as above	Same as above
	Number of Specimens	-	-	-
	Test Conditions	Critical Design Conditions of Heating and Loading	Same as above	Same as above
	Test Objectives	Verification of Aft Section Heat Shield Strength	Verification of Grew Compartment Heat Shield Strength	Verification of Forward Conical Section Heat Shield Strength
	Test Tile	Aft Section Proof Test	Crew Compartment Proof Test	Conical Section Proof Test

1.5 FLIGHT INSTRUMENTATION DEVELOPMENT TESTS (See Figure 5)

The tests presented in this section are in support of development of instrumentation for the flight test of the ablative heat shield.

1.5.1 Sensor Calibration Tests and Performance Evaluation

Thermocouple performance evaluation encompasses calibration, thermoelectric stability measurements, and transient performance under simulated re-entry heating conditions. Thermocouple calibrations shall be performed in the Avco RAD precision temperature calibration facility. Resistanceheated furnaces with stabilizing blocks shall be used in the intermediate temperature range while an optical pyrometer calibration facility shall be employed above 3000°F. NBS-calibrated platinum thermocouples and tungsten strip lamps are available as comparison standards. Repeated temperature cycling shall be accomplished in an apparatus designed specifically for studies of this type. The evaluation program shall include studies of coating interactions, oxidation effects, and vibration effects. Extensive use shall be made of X-ray, chemical analysis, and metallographic facilities in these investigations.

Plasma arc testing in the OVERS and Model 500 arcs shall be employed to check the performance of thermocouples installed in the ablating heat shield materials. Time-temperature histories obtained with chromel-alumel and tungsten-rhenium thermocouples shall be corrected for conduction errors, and these measurements then used to determine heat flux, location of the ablation surface, thermal properties, and surface temperature and emissivity. The results shall be correlated with optical measurements made during the test.

The performance of the calorimeter shall be evaluated in the presence of ablative products as well as in a clean environment. The design of the rear surface between the calorimeter plug and the adjacent materials shall be investigated to determine an optimum arrangement for ensuring essentially adiabatic conditions at the backface.

The calorimeter performance shall be conducted in the Model 500 arcs as well as a clean arc such as OVERS. The calorimeters shall be calibrated against water-cooled calorimeters, and this calibration compared with analytic predictions based on known calorimeter geometry and thermal properties. Performance evaluation and calibration under simultaneous connective and radiative heating shall be included.

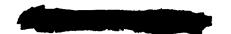
Calorimeter surface emissivity measurements shall be determined both inside and outside the plasma arc. The effect of heat input due to oxygen recombinations at the calorimeter surface shall be investigated by employing calorimeters having surfaces which are both catalytic (metal) and non-catalytic (metal oxide).



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7 8 9 10 11 12 13 14 15 16 17 11
Begin Thermocouple Testing
Prototype
Receipt of
Development Units
Design Development
Begin Calorimeter Testing
Prototype
Receipt of
Development Units
Design Development
Begin Testing Power Supply for Low Pressure Sensor
Prototype
Receipt of Development Units
Design Development
Begin Low Pressure Sensor Testing
Prototype
Receipt of Development Units
Development Development
10 MW Arc Tests for Calorimeter and Char, Ablation, and Temperature Sensors
(60 Tests)
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1962

Figure 5 INSTRUMENTATION DEVELOPMENT



1.5.2 Sensor Development Testing

Development testing is performed on all components (both purchased and designed in house) to ensure adequacy of design.

1.5.3 Static Tests

"Static" or bench testing is performed on all instruments. The purposes of these tests are to determine such parameters as sensitivity, resolution, offsets, drift, repeatability, and overall accuracy. These tests consist of subjecting the specimen to simulated or real input functions, then measuring and evaluating the response.

1.5.4 Environmental Tests

Environmental testing is performed to ensure that the instrumentation shall survive and operate properly under the expected environmental conditions. In some cases, this consists of providing an input function and monitoring the output, while the unit is being subjected to critical environmental extremes of temperature, shock, vibration, pressure, radio-frequency fields, and power supply variation. In other modes of tests, the unit under test is calibrated before, and checked after, exposure to these environments.

1.5.5 Heat Pulse Simulation Tests

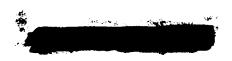
The heat pulse simulation testing is accomplished in the plasma arc facility. Samples of the heat shield material are instrumented with the flight instrumentation under evaluation. The response of the equipment is evaluated with standard laboratory instrumentation at heat inputs determined by the expected flight environment.

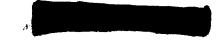
1.5.6 Effects of Space Environment on Instrumentation

Studies shall be conducted to determine the effects, on instrumentation, of the space environment, including vacuum, solar photon radiation, and the solar proton wind. Cosmic radiation and micrometeoroid effects shall also be considered.

A vacuum system capable of vacua in the below 10^{-9} mm Hg range, with provision for introduction of simulated solar photon radiation and the solar proton wind, is to be employed. This system consists of a large (200-liter) chamber, evacuated by a 1000 liter/sec electronic pump. Instrumentation samples will be placed in the chamber for evaluation of their behavior, during and after the environmental exposure.

Effects of cosmic radiation and micrometeoroids shall be studied theoretically.





1.5.7 Char Sensor

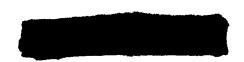
To provide accurate measurement of the char depth, the resistance of the char layer must be determined. A logarithmic amplifier shall be utilized to convert the resistance of the sensor to a d-c potential which is proportional to the resistance. The d-c voltage shall then be displayed on a quick-look direct-writing oscillograph for preliminary evaluation. This d-c voltage shall also be monitored by the existing data acquisition system for the purposes of automatic data reduction and time correlation with the arc parameters. Since sensors shall be tested in pairs, it shall be necessary to supply each sensor with separate excitation to avoid loss of data, if one sensor malfunctions. A 10-step calibrator shall be designed to simulate the expected resistance range of the sensor. This shall be used to calibrate the amplifier, oscillograph, and magnetic-tape systems prior, and subsequent, to each test. During these tests, a group of thermocouples shall be installed in the test sample to provide accurate temperature versus char data.

1.5.8 Gamma-Ray Ablation Sensor

A scintillation counter and a count rate meter shall be utilized in conjunction with cineradiography to evaluate the performance of the gamma-ray ablation sensor. As the sensor ablates, the radioactive sources are carried away by the plasma stream. Each time a source leaves the sensor, a decreasing step in the counts per second is experienced. This change in count is converted to a change in d-c voltage at the output of the count rate meter and is displayed on an oscillograph recording, and is also supplied to the data acquisition system. The cineradiographic equipment, using X-rays, shall provide a visual time history of the ablating surface and the carrying away of radioactive sources. A time generator shall be employed to give accurate time correlation between the cineradiographic equipment and the acquisition system.

1.5.9 Temperature Sensor

These temperature sensors shall be evaluated using a known temperature reference junction with measurement data supplied to both an oscillograph, for quick-look information, and to the existing data acquisition system. The use of a reference junction precludes the necessity of running long thermocouple wires from the test sample to the data systems.



2.0 QUALIFICATION TESTS

A detailed qualification test program plan is a separate documentation requirement. This section outlines the testing as presented in the detail plan (see figure 6).

2.1 QUALIFICATION TEST OF MATERIAL PANELS

Qualification testing of the material panels for the Apollo vehicle shall be conducted to demonstrate that the ablation material, bond, and manufacturing processes are suitable for use on the full-scale heat shield. The test program is intended to demonstrate that the chosen ablation materials and bond have the operational capability to withstand the expected environments of pre-flight, flight, earth orbit, lunar, translunar, and cislunar environments, as well as entry, earth landing, and recovery. The testing program will make use of the environmental testing facilities at Avco RAD, to determine the effects of environments, singly and in appropriate combinations on the panels. The order of effort will be as follows:

2.1.1 Test Procedure

Test procedures shall describe the course of action to be followed in evaluating the item under test to include (a) applicable documents, (b) specify sequence and intensity of all environments to be applied, (c) specify the number of samples, (d) means of holding or fastening the samples to laboratory equipment, (e) proposed methods of data handling and analysis, (f) laboratory facilities required, and(g) a proposed schedule of operation.

2.1.2 Evaluation

This portion of the detail program plan shall include:(a) procurement of test items, (b) the design and fabrication of fixtures, (c) scheduling of laboratory operations, (d) pre-environmental, environmental, and post-environmental testing, (e) utilization of failure analysis facilities, and(f) collection of data.

2.1.3 Reporting

This phase of the task will continue throughout the conduct of a test as needed. In the event of failure or change, up-to-date technical releases shall be issued to inform design, fabrication, testing, and other responsible personnel of progress. Following the completion of a testing program, a final report shall terminate the evaluation of the part, assembly, or complete data collection system with a complete documentation of the history of the item under test. This final document shall state recommendations for improvement of reliability, and the suitability of the test item for use



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Figure 6 QUALIFICATION TESTING

in the Apollo vehicle. Design coordination activities shall be reflected in standard failure reports, technical releases, monthly progress reports, and upon completion of the program, with a formal final qualification test report.

2.2 QUALIFICATION TESTING -- INSTRUMENTATION

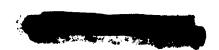
Qualification testing shall be conducted to determine by laboratory tests, the suitability and adequacy of component, subsystems, and systems for use in a flight test vehicle.

Certain select numbers of each of these units shall be subjected to a series of operational and environmental tests specified in a detail specification typical of what may be expected before and during actual flight. The performance of the units, under these conditions, shall then be evaluated and reports covering the results issued. Upon successful completion of the series of tests, a certificate of qualification shall be issued. In the event of failure, a failure report shall be issued. Throughout the testing, up-to-date technical releases shall be made.

Sensors and associated equipment that shall be used in flight tests of the Apollo vehicle for evaluation of the Avco-constructed heat shield that shall be qualified are as follows:

Test Quantity	Item							
8	Gamma-Ray Ablation Sensors							
8	Char Sensors							
8	Count Rate Meters							
8	Power Supplies							
8	Resistance Thermometers							
8	Thermopiles							
8	Calorimeters							
8	Reference Wells							
8	Pressure Monitors (Potentiometer-type)							
8	Pressure Monitors (Alphatron-type)							
8	Junction Boxes							
1	Instrumentation Tester							

The evaluation of each item shall follow the sequence described in the previous section; i. e., test procedure, evaluation, and test report.

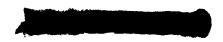




2.3 QUALIFICATION TEST OF FULL-SCALE HEAT SHIELD

The full-scale heat shield of this test vehicle shall be qualified during the qualification test of the command module by NAA/S&ID. This test shall be a joint effort, and shall be supported in a manner consistent with the requirement of the program.

The qualification test of the full-scale heat shield shall demonstrate whether the heat shield is capable for performance of its required function before, during, and after exposure to the environmental simulation of actual flight conditions. The tests for simulation flight conditions shall be contained in a separate document, qualification test procedure for the full-scale heat shield. In addition, this plan shall specify the data requirements, the instrumentation to be used, and the proposed method of data analysis. Special instrumentation shall be included to monitor the test and record data on those components for which Avco shall be responsible.



3.0 RELIABILITY DEMONSTRATION TESTS

A reliability demonstration plan has previously been submitted. It establishes and outlines the test program plan to be implemented as the reliability demonstration plan for the Apollo heat shield, (see figure 7).

Experimental verification of the reliability of the ablative heat shield panels and attachment to the substructure is to be determined by

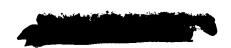
- 1. Manufacture of test panels.
- 2. Bonding of one-half of the test panels.
- 3. Nondestructive testing of both bonded and unbonded panels.
- 4. Destructive testing of a portion of both bonded and unbonded panels.
- 5. Environmental testing, less re-entry conditions, of both bonded and unbonded panels.
- 6. Nondestructive testing of environmentally tested panels.
- 7. Destructive testing of environmentally tested panels.
- 8. Simulated re-entry of environmentally tested panels.

A more detailed description of the reliability tests may be found in the Apollo Heat Shield Reliability Plan, Part IIIB. Reliability Demonstration, dated 5 June 1962, Avco RAD-SR-62-99.



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Figure 7 RELIABILLTY DEMONSTRATION TESTING



4.0 FLIGHT TESTS

Avco shall participate in the flight tests of the Apollo vehicle in the areas of system test operations plus launch operations and field support, relative to the heat shield and any Avco-supplied instrumentation sensors (see figure 8).

4. 1 SYSTEM TEST OPERATIONS

The Avco participation in the flight test program is restricted to the flight test effort related to evaluation of the heat shield. Within this general area, Avco shall evaluate the required instrumentation and provide program support, and data processing and evaluation.

4.1.1 Test Objectives

The Avco flight test objectives are

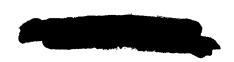
- a. Verification of the heating environment,
- b. Determination of the heat shield material performance,
- c. Verification of the analytical ablation model,
- d. Verification of the heat shield structural integrity during all flight phases.

4.1.2 Technical Plan

Avco shall assist NAA/S&ID in planning the flight test program for the orbital re-entry vehicles to provide heat shield qualification for this mission. This area of planning shall also include specification of measurements required by Avco for this evaluation, but which are assigned to be supplied by NAA/S&ID for other purposes also. For example, vehicle dynamics, vibration, strain measurements, and acoustical noise data, as well as range data, such as atmospheric conditions and tracking, fall into this category.

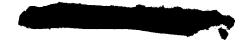
4.1.3 Post-Flight Data Reduction

Avco shall provide post-flight data reduction for ablation data, char measurements, material temperature, and calorimeters. In addition, this reduction shall be provided for pressure and backface temperature measurements. Specific assumptions for the format of data to be supplied to Avco are as follows:



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Figure 8 LAUNCH OPERATIONS AND FIELD SUPPORT



- a. All data to be furnished on magnetic tape or on punched cards in IBM floating point format.
- b. NAA/S&ID shall define:
 - 1) Ascent trajectory.
 - 2) Orbital parameters.
 - 3) Re-entry trajectory.
- c. NAA/S&ID shall provide the following aerodynamic data:

A time history of the stagnation point in terms of vehicle body axis (in other words, a time history of the vehicle angle of attack and angle of side slip).

- d. Time histories of the following data shall be provided (magnetic-tape format assumed):
 - l) Pressures.
 - 2) Material temperatures.
 - 3) Calorimeters.
 - 4) Backface temperatures.

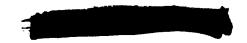
4.1.4 Data Environment and Analysis

Avco shall provide flight test data evaluation for the earth orbital flights insofar as the evaluation of the heat shield is concerned. The specific effort to be performed is outlined below:

- a. Post-flight analysis of specimens from the recovered heat shield (visual, X-ray, ultrasonic, chemical analysis, metallographic analysis, char-layer analysis, and bed strength analysis).
- b. Heating
 - 1) Ascent

For the ascent portion of the flight, it is considered that the vehicle will be ablating and, therefore, the time requirements for analysis will be similar to that of a regular re-entry. In essence, pressure and calorimeter data shall be used to define the cold-wall





heating pulse; hot-wall corrections shall be applied, and then, the ablation and conduction program shall be used to determine the influence of the effective heating pulse on the heat shield material.

2) Re-entry heating

For the re-entry phase, analyses similar to those conducted for ascent shall be accomplished. The estimates assume that the re-entry velocity is sufficiently low to preclude nonequilibrium radiation.

3) Orbital phase

The orbiting phase of the flight is somewhat of a problem from a standpoint of thermodynamic analysis. The ground rules specified indicate that approximately 17 orbits per day will occur for a period of 14 days, which would yield a total of 238 orbits. To analyze the heat pulse for each orbit would be an extremely costly procedure. Therefore, it was assumed that 10 orbits would be evaluated per flight, and only a general review of the thermodynamic data on all other orbits would be conducted.

c. Structure

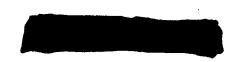
It is assumed that NAA/S&ID will provide strain data in reduced form corrected for all spurious effects. The data should be presented as a function of time for the re-entry and ascent portions of the flight. These data would be utilized for comparison to the output of the thermal stress program. (This program has as an input the temperature profile through the material and produces the strain history for a given point in the heat shield or support structure.)

d. Vibration and Loads

It is assumed that NAA/S&ID will provide sufficient data to define the inertial loading environment for the heat shield during the ascent and re-entry portions of the flight. In addition, it is assumed that pertinent vibration data would be provided in plotted form in standard vibration analysis terms (i.e., g square per cps as a function of frequency). The vibration and loading information would be compared to the heat shield design criteria to assure that the specifications involved in the heat shield design agree with the flight test data.

4.2 LAUNCH OPERATIONS AND FIELD SUPPORT

Avco participation in the launch operations and field support shall be primarily in two areas: (a) The checkout of any Avco-supplied instrumentation sensors,



and (b) inspection and checkout of the heat shield prior to launch. In addition, it is planned that a technical liaison representative shall be provided at NAA/ S&ID during the period that the completed command module is undergoing systems installation. This representative will provide technical liaison during the period of systems installation insofar as the heat shield may be involved.

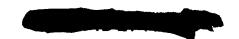
Avco shall provide field test support at AMR for checkout of Avco-supplied instrumentation and of the heat shield prior to flight. A field crew will be provided in a facility to be supplied by NAA/S&ID or NASA and this crew will provide the necessary field checkout, maintenance, repairs, or other technical liaison between Avco and NAA/S&ID during the period of field checkout operations. In addition, logistics support will be supplied, engineering coordination, configuration control, and necessary liaison and support.

4.2.1 Scope

The scope of the Avco field support is based on the following assumptions:

- a. All handling and checkout of the vehicle other than that specifically related to the heat shield and Avco-supplied instrumentation will be provided by NAA/S&ID.
- b. NASA or NAA/S&ID-supplied facilities will be utilized and space will be supplied for the Avco team of approximately three engineers and five technicians.
- c. No field support is planned at sites other than AMR.
- d. Only flight test vehicles are included in the launch operations and field support plan. Support of the environment, static test, or other test articles is not planned.
- e. Only minor field repairs can be made within the scope of the program plan. Replacement of a complete heat shield tile is considered a major repair and is specifically not included as a field operation.
- f. Recovery site support is not planned, and the post-flight operations to be performed by Avco are defined under the systems test operations under section 4.1.
- g. No extensive facility items or special test equipment will be required.
- h. Avco shall perform a transducer system checkout independent of the telemetry system.





- i. Access to instrumentation and cabling is permissible for checkout and repair/replacement purposes. Disassembly of the capsule and removal of the inner capsule may be necessary; the responsibility for capsule disassembly and re-assembly lies with NASA and/or NAA/S&ID.
- j. NASA and/or NAA/S&ID will perform a systems checkout of Avco transducers through the capsule telemetry. Avco shall provide such support as required for sensor stimulation only.

4.2.2 Instrumentation

The testing, checkout, and calibrating which Avco shall perform on the instrumentation system shall ensure compliance of the transducer system with established requirements. This shall be accomplished independently of the capsule telemetry system, either by direct access to the individual components or through a junction box. The following determinations shall be made:

- a. The resistance of each transducer.
- b. The ratio of each transducer setting.
- c. The isolation of each transducer from ground.

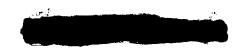
Items or system which fail test, and the data which are considered a prime objective, shall be repaired or replaced to the extent possible.

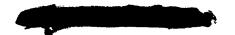
Additionally, Avco shall obtain a record of the reduced data obtained from Avco transducers through the capsule telemetry system. They shall be analyzed to ensure intersystem compatibility and signal-to-noise ratio. Avco shall provide assistance via sensor stimulation, advisory support, and test monitoring capacities only. Telemetry power, signal reception and recording, and data reduction shall be the responsibility of the system contractor. Avco shall provide only minor equipment for these purposes.

4.2.3 Heat Shield

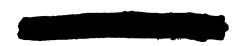
The testing and re-work which Avco shall perform on the heat shield shall consist of:

a. A comprehensive visual inspection of the heat shield. Particular emphasis shall be placed on determination of the existence of cracks, abrasions, and other degradations. Re-work capability and operations shall be limited to filling of minor cracks, and to repainting of scuffed areas. Major repainting, or the replacement of tiles may be accomplished at the factory only.





- b. An ultrasonic inspection of the bond between the heat shield and the structure. Existing pulsed-echo techniques shall be used for this purpose to the extent possible. However, since the heat shield echotransmission characteristics are not fully defined or known at this time, new equipment and techniques may be required.
- c. Eddy-current test devices may be employed to determine the amount of moisture absorption. Standard equipment and techniques are currently deemed practical.





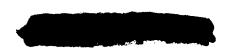
5.0 END-ITEM ACCEPTANCE TESTS

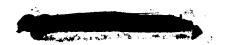
A detailed end-item acceptance test plan has been prepared and submitted to NAA/S&ID as a separate documentation requirement. This section is a summary of this document.

Comprehensive receiving inspection and in-process inspection test programs shall be conducted to provide valuable inspection records for review when the end-item tests are performed on a 100 percent basis. Some end-item tests which cannot be performed on the fully assembled end items, shall be conducted as part of the in-process tests.

Acceptance test for each end item shall consist of the following:

- 1. A thorough visual examination of the item.
- 2. Drawing conformance check shall be performed consisting of mechanical inspections and a fit check.
- 3. Nondestructive tests shall be conducted, including radiographic tests, ultrasonic tests, eddy-current (RADAC) tests, and dielectric tests.
- 4. The mass parameter of weight shall be checked.
- 5. Electrical and functional tests shall consist of dielectric strength, insulation resistance, continuity of transducers and associated cables, voltage output, and calibration verification.
- 6. Environmental tests shall be performed to simulate temperature, humidity, and vibration environments. These tests shall assure integrity of the heat shield material, instrumentation and wiring, and the bonding strength.

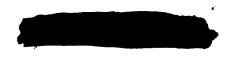




6.0 SPECIAL TEST EQUIPMENT

The detail requirements for additional special test equipment to support the Apollo Program together with complete descriptions and utilization are contained in the document numbered Avco RAD-MS-62-78, Formal Application For Special Test Equipment, dated 11 June 1962.

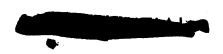
A summary list of special test equipment and use is shown in section 6.1. The required installation to meet the program requirements schedules are shown in section 6.2. The establishment of the special test equipment shall involve the adaptation and modification of existing equipment, as well as the design and construction of additional items. Insofar as is practical and economical, standardized components shall be utilized in the fabrication and assembly of special test equipment as indicated in the referenced detailed descriptions.



6.1 COMPLETE LIST OF REQUIREMENTS FOR SPECIAL TEST EQUIPMENT

Item No.	Quantity	Description
1	1	Modifications of Vacuum Chamber (Increased Capability) Use: Development, qualification, and acceptance testing of large material samples
2	4	Thermal and Moisture Expansion Test Equipment Use: Determination of expansion and contraction of heat shield materials with changes in temperature and humidity
3	1	Special Testing Equipment, Ultrasonics Use: Develop procedures to facilitate quality of bond, control of molding process, and acceptance testing
4	1	Gerber Digital Reader Model GDDRS-3B-1 with IBM 12 Position Output Writer Use: Obtain data in digital form automatically
5	6	Quartz Lamp Furnace Use: Heating of composite panels
6	4	Panel Loading Fixture Use: Loading of composite panels
7	4	Lapped Tile Panel Loading Fixture Use: Loading of lapped tile composite panel
8	3	Loading Fixtures (Proof Tests) Use: Simulation of flight loading to entire sections
9	3	Heating Fixtures (Proof Tests) Use: Heating of entire sections to simulate critical design conditions
10	92	Displacement Transducer (LVDT) Use: Determine deflection of composite panels
11	1	Cold Chamber Test Facility Use: Environmental testing
12	1	Convective and Radiative Heat Transfer Rate Distribution Use: Simulate re-entry conditions at various angles of attack

Item No.	Quantity	Description
13	1 .	Solar Absorptivity Thermal Emittance Ratio System Use: Measure ratio of solar absorptivity to thermal emittance
14	1	Laminar and Turbulent Pipe Tests Use: Connection of vacuum system into the 10- megawatt arc facility
15	1	Vacuum Pump Oil Reclaimer Use: Reclaim contaminated vacuum pump oil
16	1	Simulator for Programmed Re-entry Use: Modify OVERS facility to permit programmed simulation of radiative and convective heat flux
17	1	Radiation Simulator Use: Superposition of radiative heat flux on convective heat flux produced by existing OVERS facility
18	1	High Temperature Thermocouple Fabrication Use: High temperature operation in ablating materials
19	1	Low Pressure Sensor Calibration Use: Calibration of the low pressure sensor
20	1	Weight and Center-of-Gravity Fixture Use: Weigh and determine center of gravity of vehicles
21	1	Char and Ablation Sensor Testing Use: To provide approximate instrumentation, to facilitate evaluation of sensor operation.



6,2 SPECIAL TEST EQUIPMENT SCHEDULE REQUIRED INSTALLATION MILESTONES

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